Operational Applications of ET Mapping in California

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Kent Frame, Bekele Temesgen, CA Dept. of Water Resources

Justin Huntington, Charles Morton, Desert Research Institute

2015 International Workshop on Evapotranspiration Mapping for Water Security

Washington, DC
15 September 2015

Project Partners and Stakeholders

Water Management
California Department of Water Resources (CDWR)

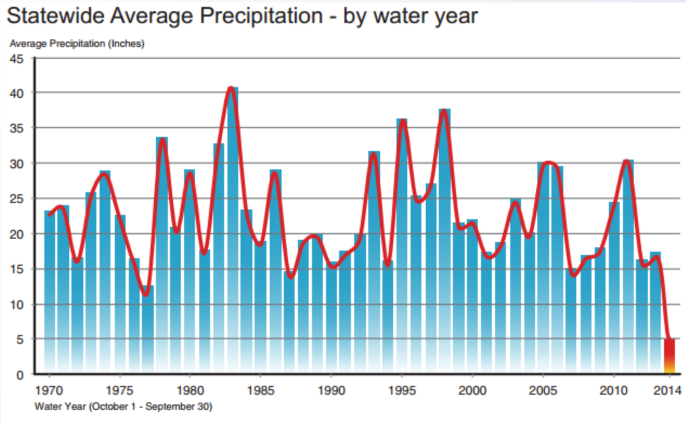
Agriculture
Western Growers Association, E & J. Gallo, Booth Ranches, Chiquita, Constellation Brands, Del Monte Produce, Driscoll's Dole, Inc., Farming D, Fresh Express, Pereira Farms, Ryan Palm Farms, Tanimura & Antle, CDFA

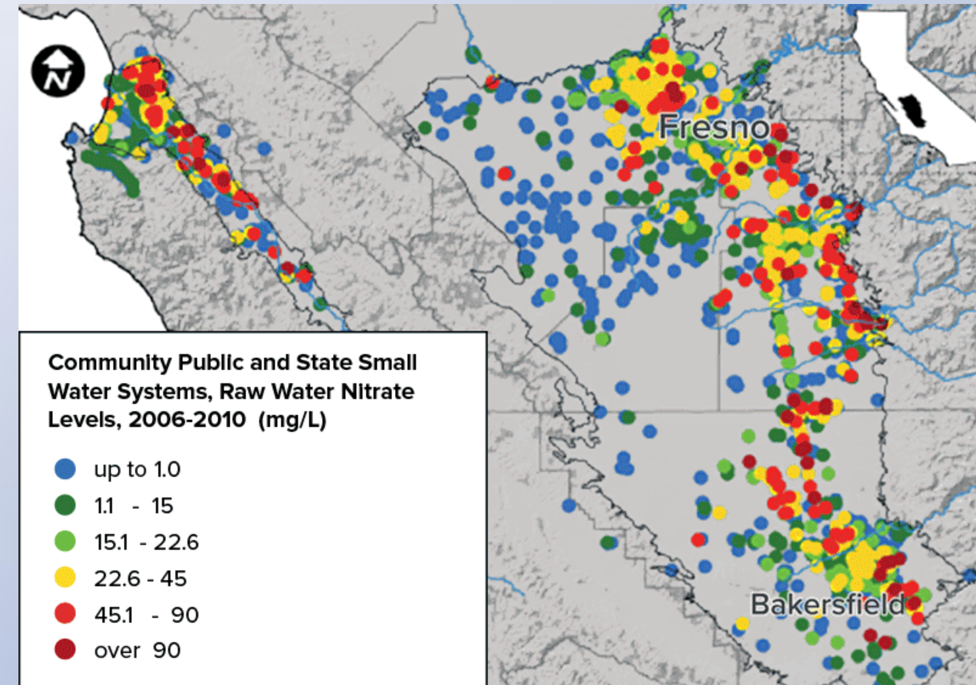
Research and Extension
Center for Irrigation Technology / CSU Fresno, USDA ARS / NRCS, Univ. of California Cooperative Extension / UC Davis, Desert Research Institute, USGS

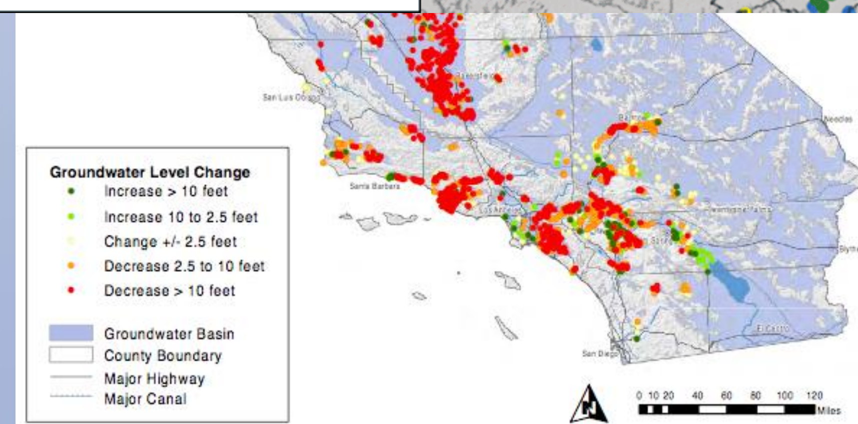
California Agriculture

- $46.4 B in cash farm receipts in 2013 from 78,000 farms
- Major domestic/international supplier of specialty crops
- Half of US-grown fruits, nuts, vegetables
- ~400 different crop types grown
- 2-3 crop rotations per year
- ~7 million acres of irrigated agriculture in the Central Valley

Threats to Water Supplies and Water Quality in California





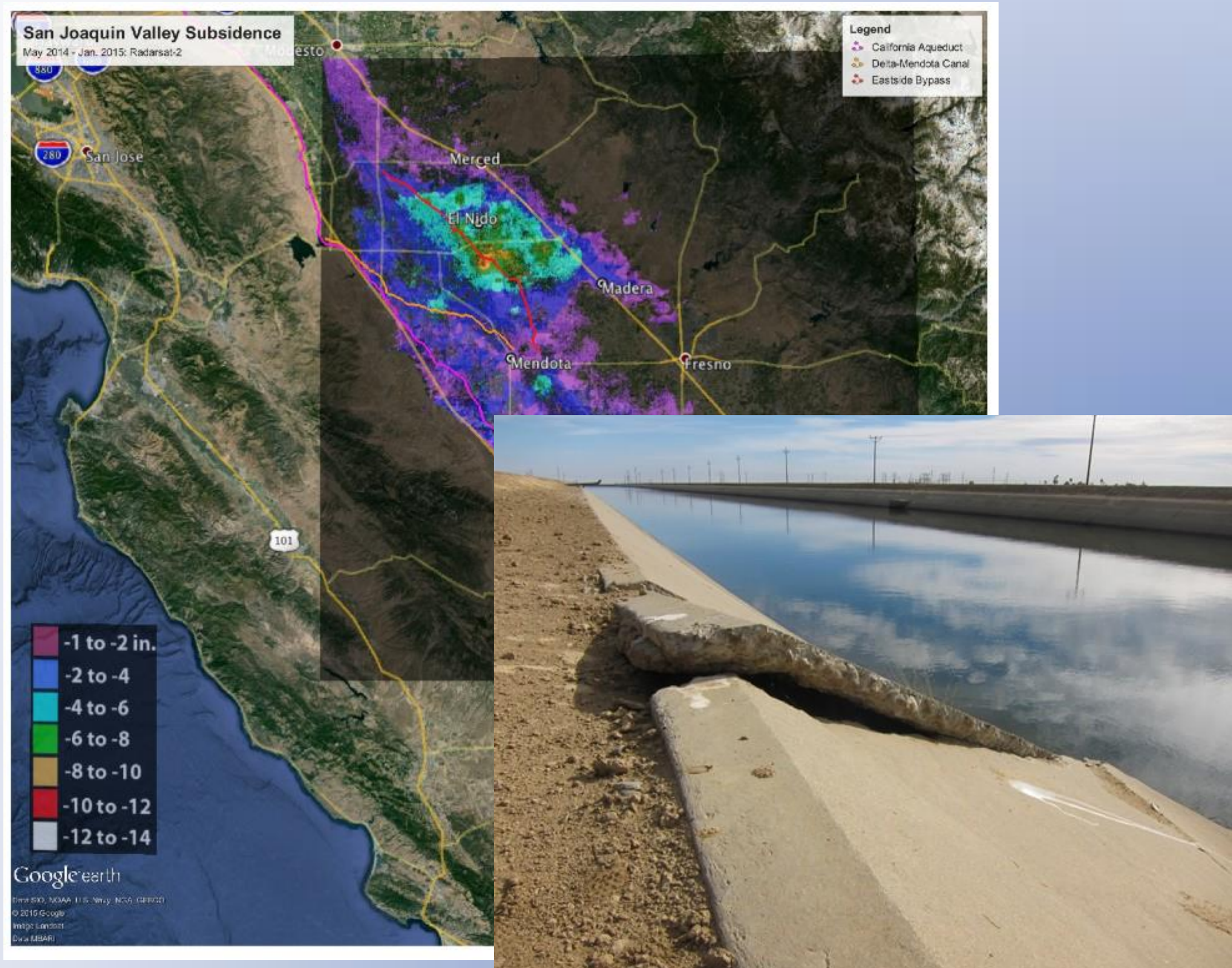


*Groundwater level change determined from water level measurements in wells. Map and chart based on available data from the DWR Water Data Library as of 07/15/2015. Document Name: S2015_S2012_DM_20150717 Updated: 07/17/2015 Data subject to change without notice.

- **2013 driest calendar year on record**
- **2014 warmest year on record**
- **In 2014, surface water allocations were <10% of full allocation**
- **2015 allocations are 0-20% of full allocation**
- **Water qual. and groundwater legislation**

Groundwater Pumping and Subsidence

San Joaquin Valley Ground Subsidence, May, 2014 – Jan., 2015



Farr et al., 2015

http://www.water.ca.gov/groundwater/docs/NASA_REPORT.pdf

Quantifying Benefits of Using ET Information in Irrigation Management

Water, Yield and Total Benefits to Farmers from CIMIS				
Crop	Water $US [+]	Yield[++] $US	Total $US	**Benefit/Hectare $US**
Trees and Vines Sample				
Almonds	246,000	2,426,500	2,672,500	**408**
Apples	900	13,900	14,800	**366**
Avocados	-141,350[*]	738,000	596,500	**760**
Grapes	100,850	1,336,500	1,437,3500	**730**
Pistachios	370,150	6,755,000	7,125,000	**630**
Plums	556	12,445	13,000	**402**
Vegetable Sample				
Artichoke	2,500	326,200	328,700	**160**
Broccoli	2,750	106,100	108,850	**730**
Cauliflower	5,750	334,100	339,850	**870**
Celery	3,350	345,750	349,100	**1700**
Lettuce	26,000	1,361,000	1,387,000	**920**
Field Crop Sample				
Alfalfa	47,790	325,700	373,500	**100**
Cotton	345,300	810,500	1,155,800	**110**

Source: http://www.cimis.water.ca.gov/cimis/resourceArticleOthersTechRole.jsp

[+]Money saved due to reduced water bill resulting from using CIMIS.

[++]Increased income from increased yield resulting from using CIMIS.

[*]Negative number indicates increased water use with CIMIS.

Average reduction in total applied water: 13%

Average increase in yields: 8%

DWR, 1997

Parker et al., 1996

Advancing ET-Based Irrigation Management

E&J. Gallo Winery

Dole®

100 UC Cooperative Extension | University of California Agriculture and Natural Resources

Constellation Brands

california almonds™
Almond Board of California

Driscoll's®
ONLY THE FINEST BERRIES™

SureHarvest

Approach: Combining Surface and Satellite Data

Standard FAO-56 approach for incorporating information on weather / crop stage into irrigation mgmt. practices:

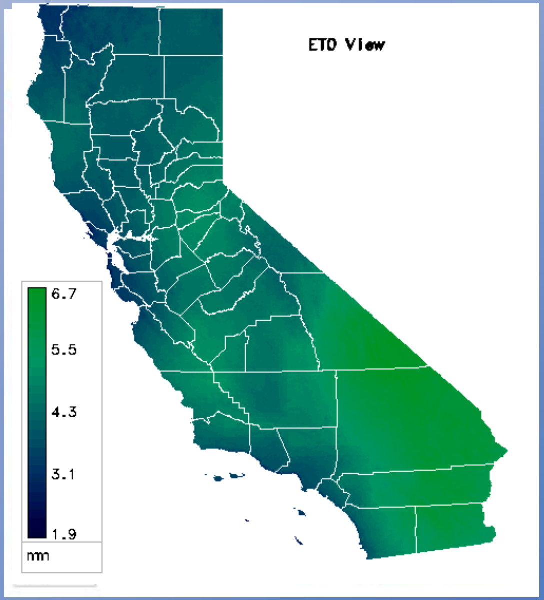
$$ET_c = ET_o * (K_{cb} + K_e)$$

CIMIS ↗ ↖ *Satellite*

Photo credit: DWR CIMIS

California Irrigation Management Information System (CIMIS)

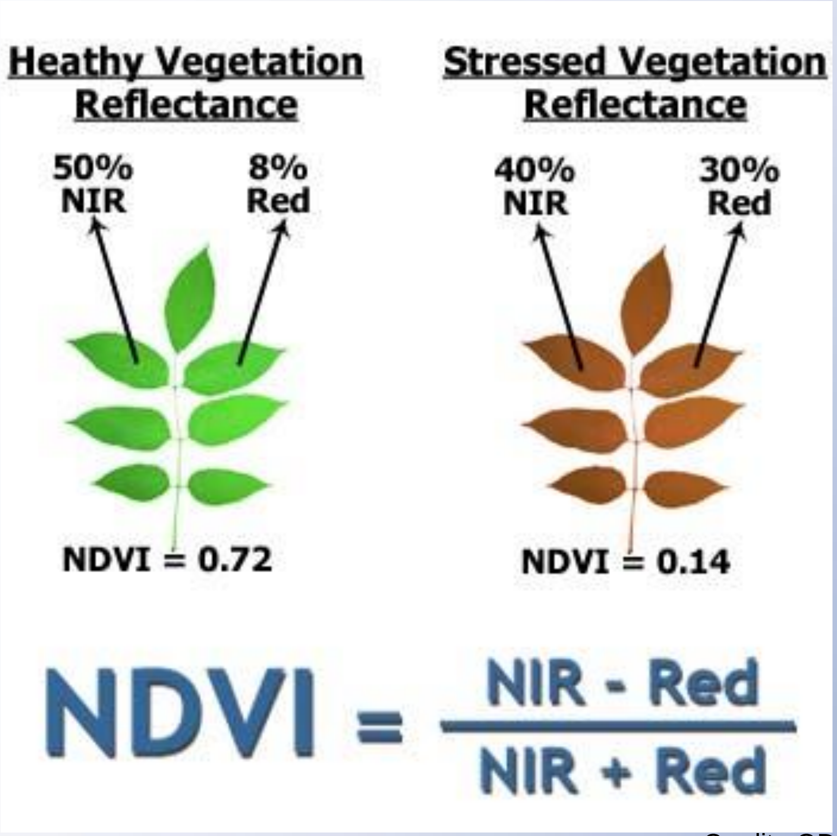
- Operated by CA DWR since 1982
- >140 stations currently providing daily measurements of ET_o
- **Spatial CIMIS** data now available for CA; 2km statewide grid, daily
- Crop coefficient mapping identified by CA DWR as high priority need for CIMIS



Spatial CIMIS ET_0

Approach: Mapping Basal Crop Coefficients

Normalized Difference Vegetation Index



Credit: ODIS

Commonly used remote sensing index of vegetation condition

Step 1:
NDVI → Fractional Cover (F_c)

- Based on studies by Trout et al., 2008; Johnson et al., 2012

Step 2:
F_c → K_{cb}

- Allen and Perreira, 2009; Bryla et al., 2010; Grattan et al., 1998; Hanson & May, 2006; Lopez-Urrea et al., 2009 . . .

Step 3:
$ET_{cb} = ET_0 * K_{cb}$

- Follows FAO-56 approach
- ET_0 from CIMIS
- Calculation of soil evaporation and crop stress via soil water balance

Approach: Combining Surface and Satellite Data

$$ET_{cb} = ET_o * K_{cb}$$

CIMIS (AgriMet, AZMET, CoAgMet) → ET_o

satellite → K_{cb}

Standard K_c Profile (manual)

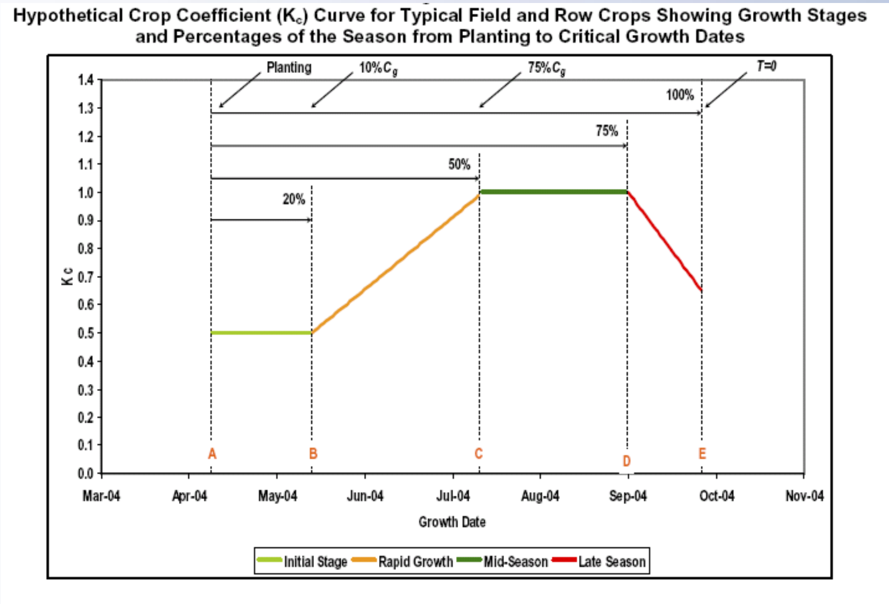
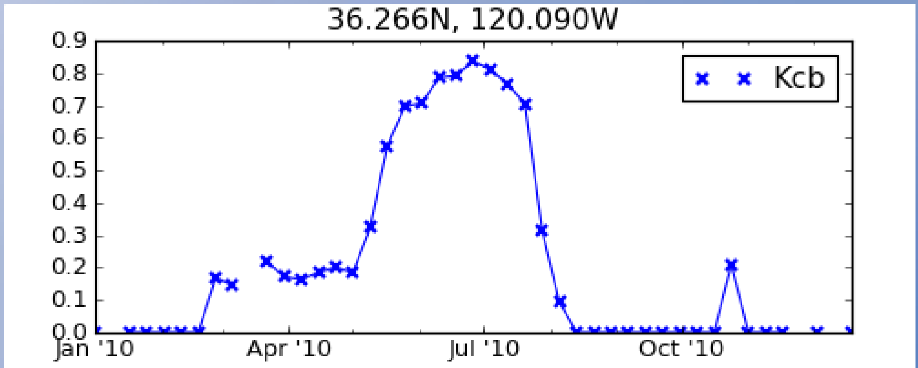


Figure credit: 2005 California Water Plan Update

TOPS-SIMS K_{cb} Profile (Automated, Satellite-derived)



Kc profiles via: 1) reflectance based algorithms (NASA Ames); and 2) METRIC surface energy balance (DRI, J. Huntington)

Satellite Irrigation Management Support (SIMS): Objectives

1) Develop near real-time estimates of crop water requirements from satellite data to assist growers in optimizing irrigation, and water managers in improving estimates of agricultural water requirements

2) Provide web and mobile data interfaces to increase the ability of the agricultural community to access and use satellite data in irrigation management and crop monitoring

Approach:
Satellite Irrigation Management Support (SIMS) Framework

1. Integration of satellite and surface measurements
2. Prototyping accelerated by NASA high end computing resources
3. Integration with irrigation management tools (CropManage, VSIM)
4. Freely available data
5. Outreach and education through partnerships with CA ag extension services and Western Growers

Melton et al., 2012, IEEE JSTARS

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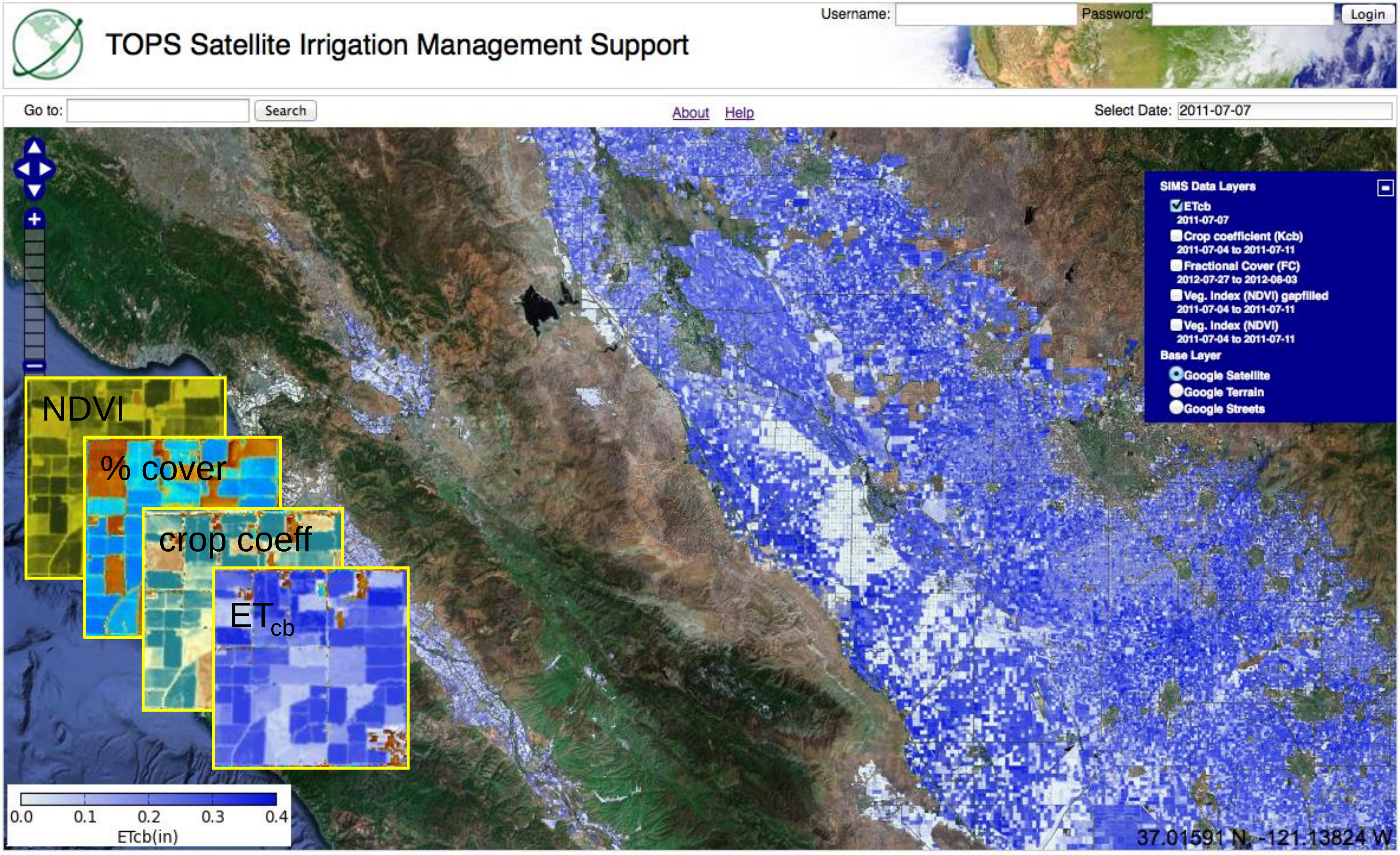
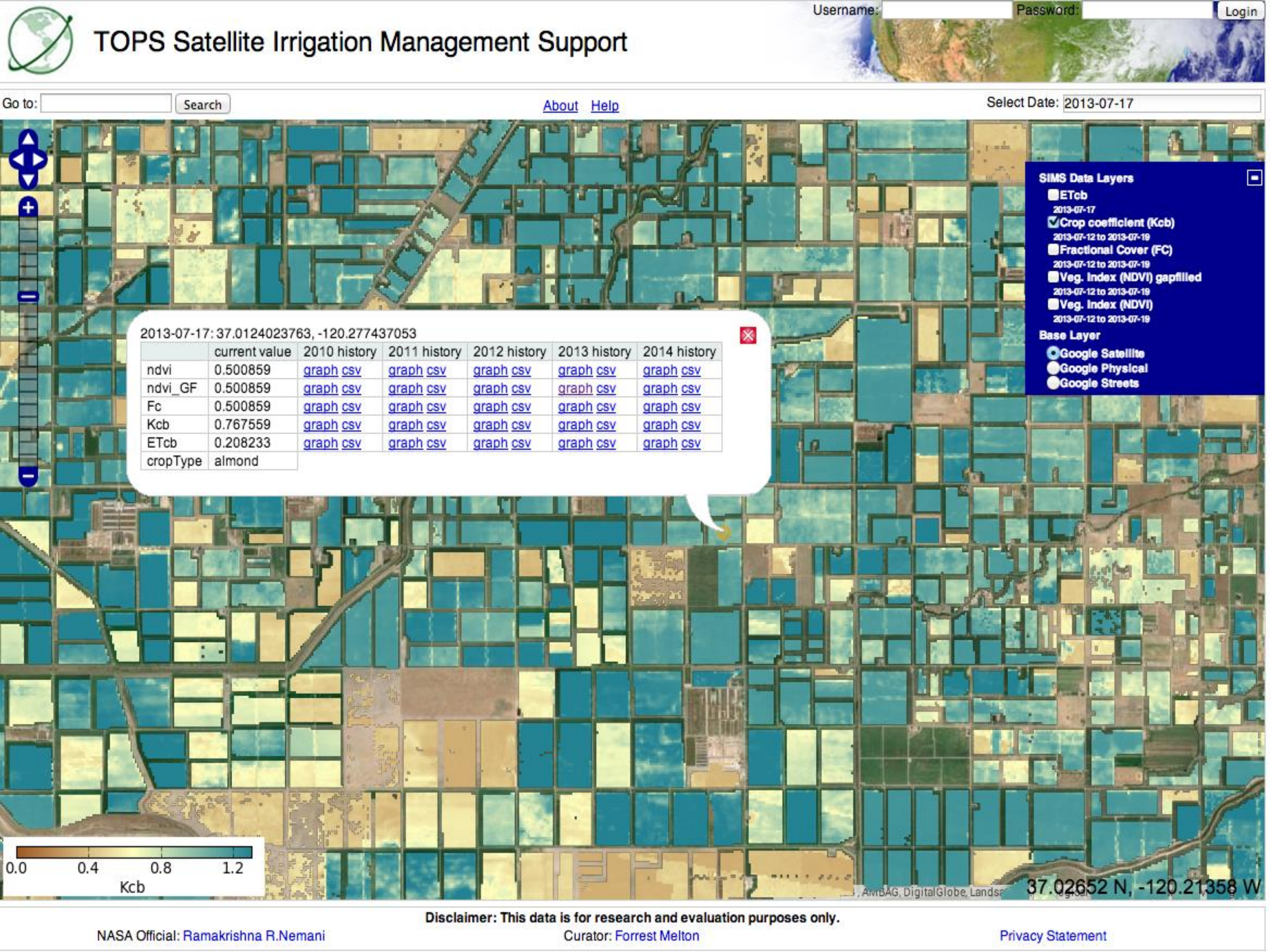
Highlights: SIMS Web Interface

- Prototype system completed; on-line web and mobile interfaces released to project partners and currently publicly accessible.
- System currently being tested by multiple growers
- Integration with UCCE CropManage irrigation management tool
- Prototype calculator for on-farm water use efficiency metrics completed

SIMS Web Interface showing example of daily ETcb for San Joaquin Valley

Satellite Irrigation Management Support (SIMS) Web Services




TOPS Satellite Irrigation Management Support
Username:
Password:
Login
Go to:
Search
About
Help
Select Date: 2013-07-17
SIMS Data Layers
ETcb
2013-07-17
Crop coefficient (Kcb)
2013-07-12 to 2013-07-19
Fractional Cover (FC)
2013-07-12 to 2013-07-19
Veg. Index (NDVI) gapfilled
2013-07-12 to 2013-07-19
Veg. Index (NDVI)
2013-07-12 to 2013-07-19
Base Layer
Google Satellite
Google Physical
Google Streets
2013-07-17: 37.0124023763, -120.277437053
	current value	2010 history	2011 history	2012 history	2013 history	2014 history
ndvi	0.500859	graph csv	graph csv	graph csv	graph csv	graph csv
ndvi_GF	0.500859	graph csv	graph csv	graph csv	graph csv	graph csv
Fc	0.500859	graph csv	graph csv	graph csv	graph csv	graph csv
Kcb	0.767559	graph csv	graph csv	graph csv	graph csv	graph csv
ETcb	0.208233	graph csv	graph csv	graph csv	graph csv	graph csv
cropType	almond					
0.0
0.4
0.8
1.2
Kcb
AMBAG, DigitalGlobe, Landsat
37.02652 N, -120.21358 W
Disclaimer: This data is for research and evaluation purposes only.
NASA Official: Ramakrishna R.Nemani
Curator: Forrest Melton
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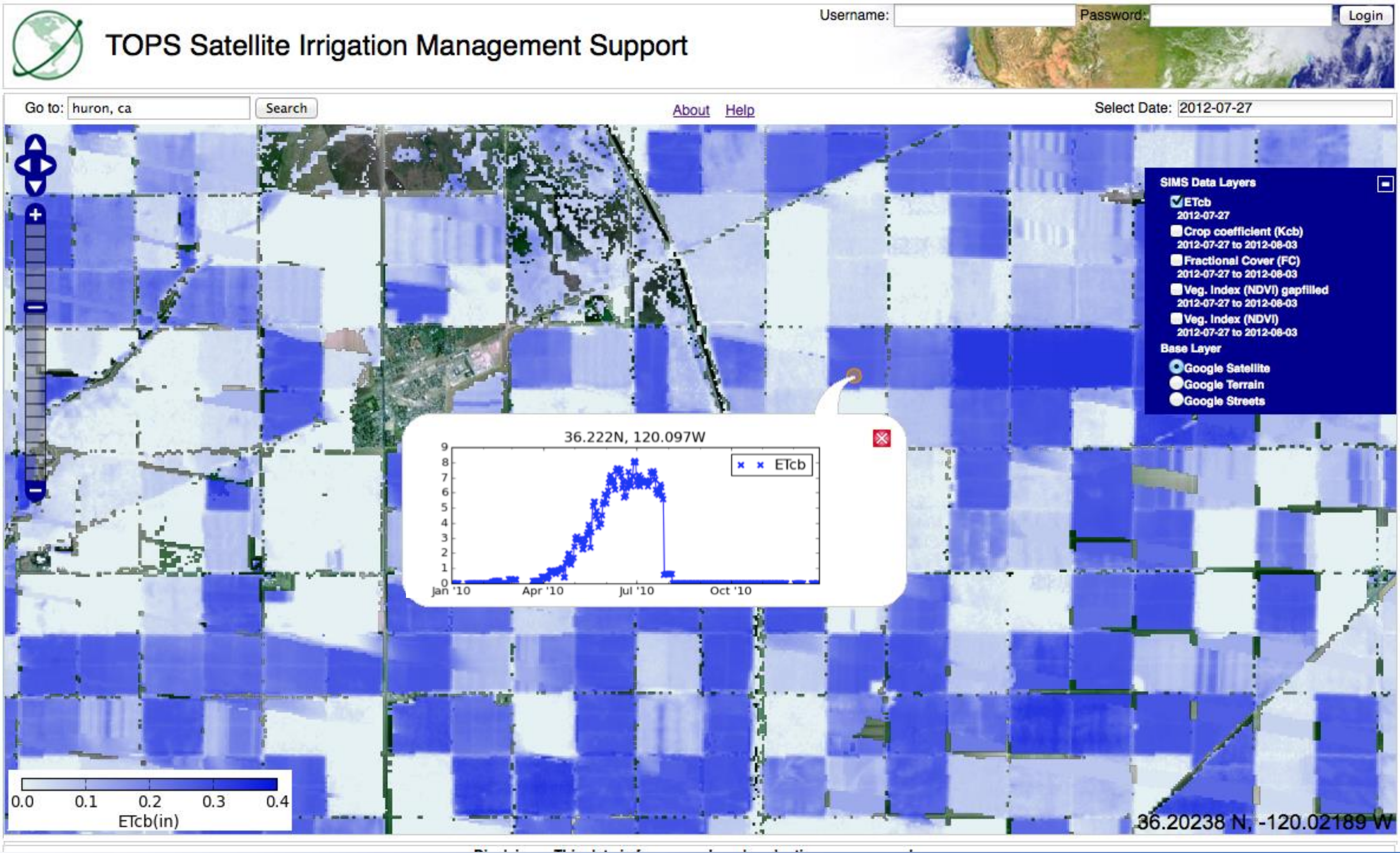
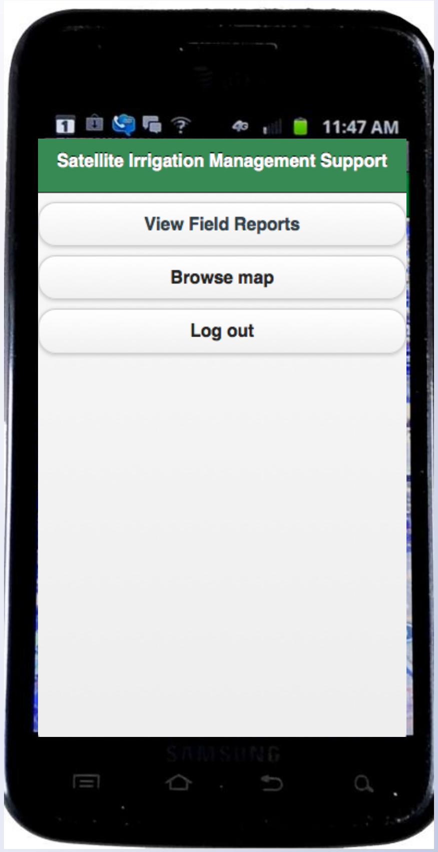
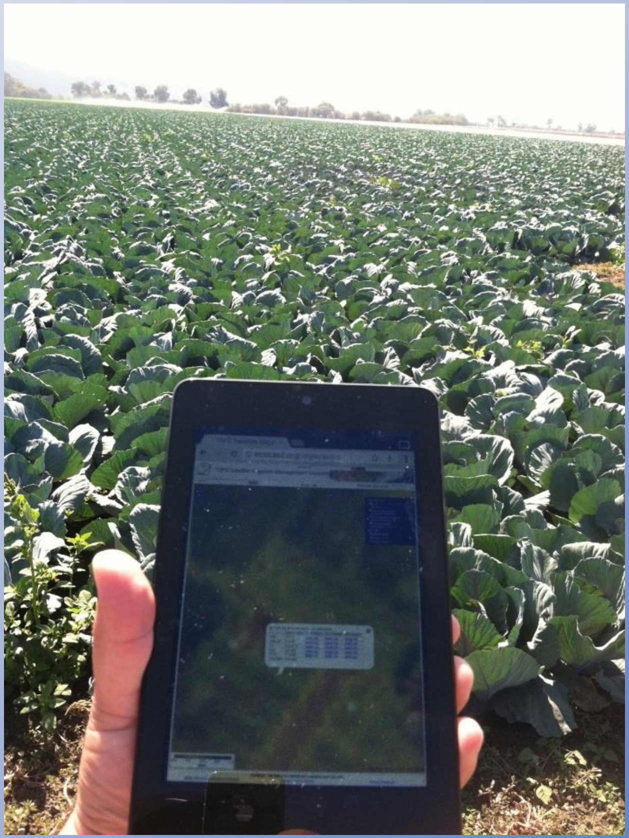
Satellite Irrigation Management Support (SIMS) Framework



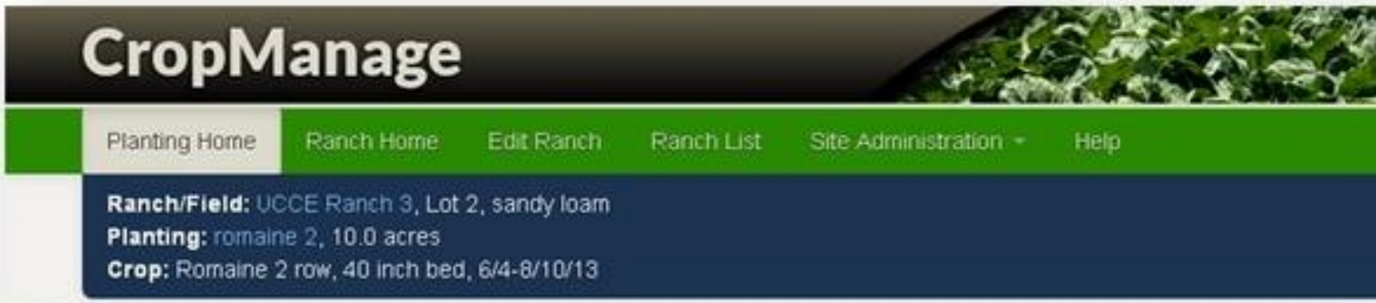
Delivering Data to the Field: Mobile Interfaces





Mobile-based interfaces important for enhancing access to data

API for Integration with Other Web-based Tools



Irrigation Summary

Show / Hide Columns | Reset Column Order | Show Previous Columns | Show Next Columns

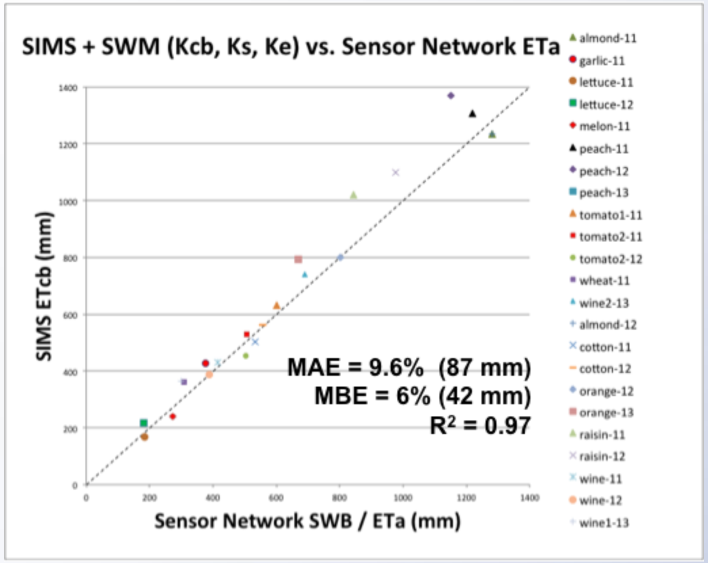
Water Date	Irrigation Method	Recommended Irrigation Interval (days)	Recommended Irrigation Amount (inches)	Recommended Irrigation Time (hours)	Irrigation Water Applied (inches)	Kc	Canopy Cover (%)	Average Reference ET (inches/day)	Total Crop ET (inches)
6/4/13	Germination Sprinkler	N/A	N/A	N/A	0.75 in	0.00	0	0.00	0.00
6/5/13	Germination Sprinkler	1.6	0.22 in	0.72 hrs	0.45 in	1.00	0	0.14	0.14
6/7/13	Germination Sprinkler	1.9	0.36 in	1.18 hrs	0.30 in	0.70	0	0.17	0.23
6/9/13	Germination Sprinkler	1.7	0.39 in	1.29 hrs	0.45 in	0.70	0	0.18	0.25
6/12/13	Sprinkler	3.1	0.28 in	0.95 hrs	0.30 in	0.48	1	0.15	0.21
6/16/13	Sprinkler	2.9	0.40 in	1.33 hrs	0.45 in	0.37	1	0.20	0.30
Totals			1.64 in	5.47 hrs	2.70 in				1.13 in

New Watering | View Rainfall Data

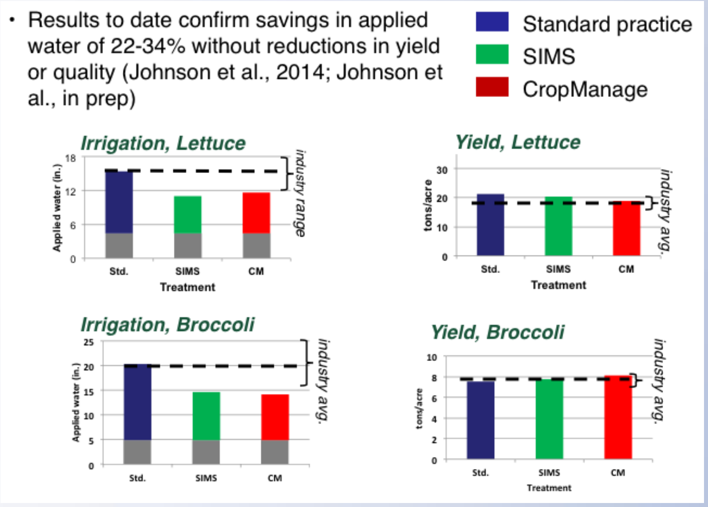
First Previous 1 Next Last

Show All Rows

Highlights: Accuracy Assessment



Seasonal ETcb from SIMS + FAO-56 SWB vs field measurements of ET.



Results from yield trials completed in 2012 and 2013 for lettuce and broccoli.

Accuracy Assessment

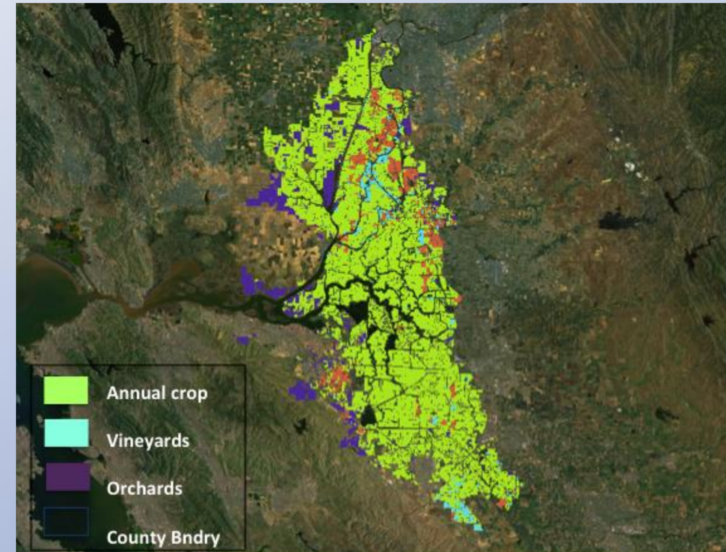
- Field validation campaign completed in partnership with partner growers, CA DWR, CSU Fresno, and USDA ARS.
- Data collected for more than 14 crops at 30 sites using eddy covariance, surface renewal, soil moisture sensor networks.
- Results highly encourage for seasonal and daily comparisons.

Yield Trials and Demonstration Projects

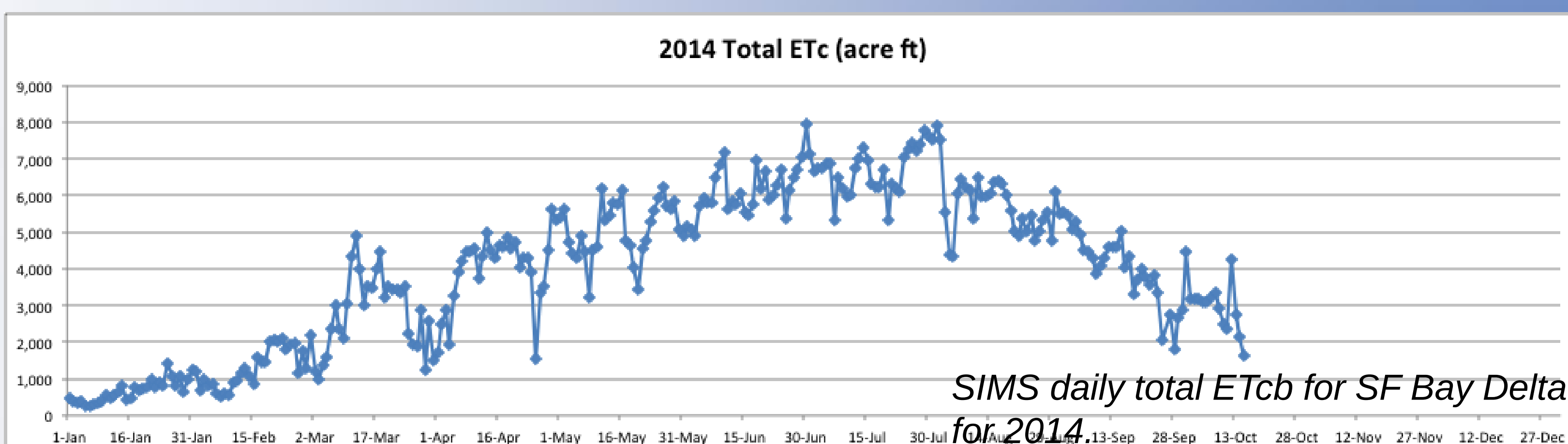
- Field irrigation trials completed in partnership with USDA ARS and UCCE.
- Results from 2 year study demonstrated 20-40% reduction in applied irrigation with equivalent or improved yields for lettuce and broccoli crops.
- CDFA supporting additional trials in 2015 and 2016.

Highlights: Mapping ET in the CA Delta

- Fully automated mapping of crop water use in California Delta
- Seasonal results within ~5% of CDWR CalSIMETAW and SEBAL → real-time mapping for Delta water management
- Pilot study led by UC Davis initiated in 2015/2016 for real-time mapping of California Delta to aid in salinity management

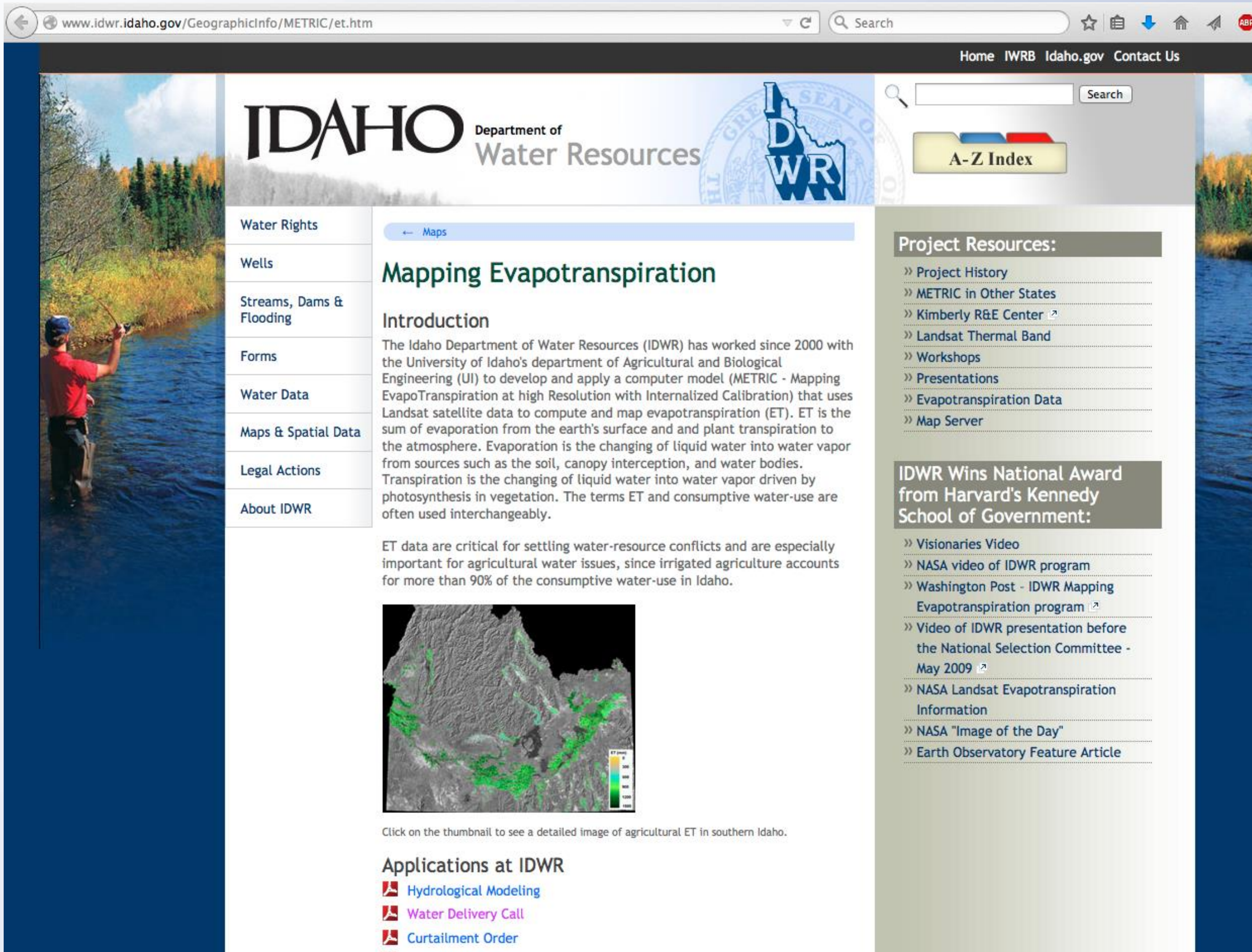


Map of SF Bay Delta showing major crop categories.



SIMS daily total ETcb for SF Bay Delta for 2014.

Mapping Evapotranspiration with Internalized Calibration (METRIC)


www.idwr.idaho.gov/GeographicInfo/METRIC/et.htm

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IDWR

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- Streams, Dams & Flooding
- Forms
- Water Data
- Maps & Spatial Data
- Legal Actions
- About IDWR

← Maps

Mapping Evapotranspiration

Introduction

The Idaho Department of Water Resources (IDWR) has worked since 2000 with the University of Idaho's department of Agricultural and Biological Engineering (UI) to develop and apply a computer model (METRIC - Mapping EvapoTranspiration at high Resolution with Internalized Calibration) that uses Landsat satellite data to compute and map evapotranspiration (ET). ET is the sum of evaporation from the earth's surface and and plant transpiration to the atmosphere. Evaporation is the changing of liquid water into water vapor from sources such as the soil, canopy interception, and water bodies. Transpiration is the changing of liquid water into water vapor driven by photosynthesis in vegetation. The terms ET and consumptive water-use are often used interchangeably.

ET data are critical for settling water-resource conflicts and are especially important for agricultural water issues, since irrigated agriculture accounts for more than 90% of the consumptive water-use in Idaho.

Click on the thumbnail to see a detailed image of agricultural ET in southern Idaho.

Applications at IDWR

- Hydrological Modeling
- Water Delivery Call
- Curtailment Order

Project Resources:

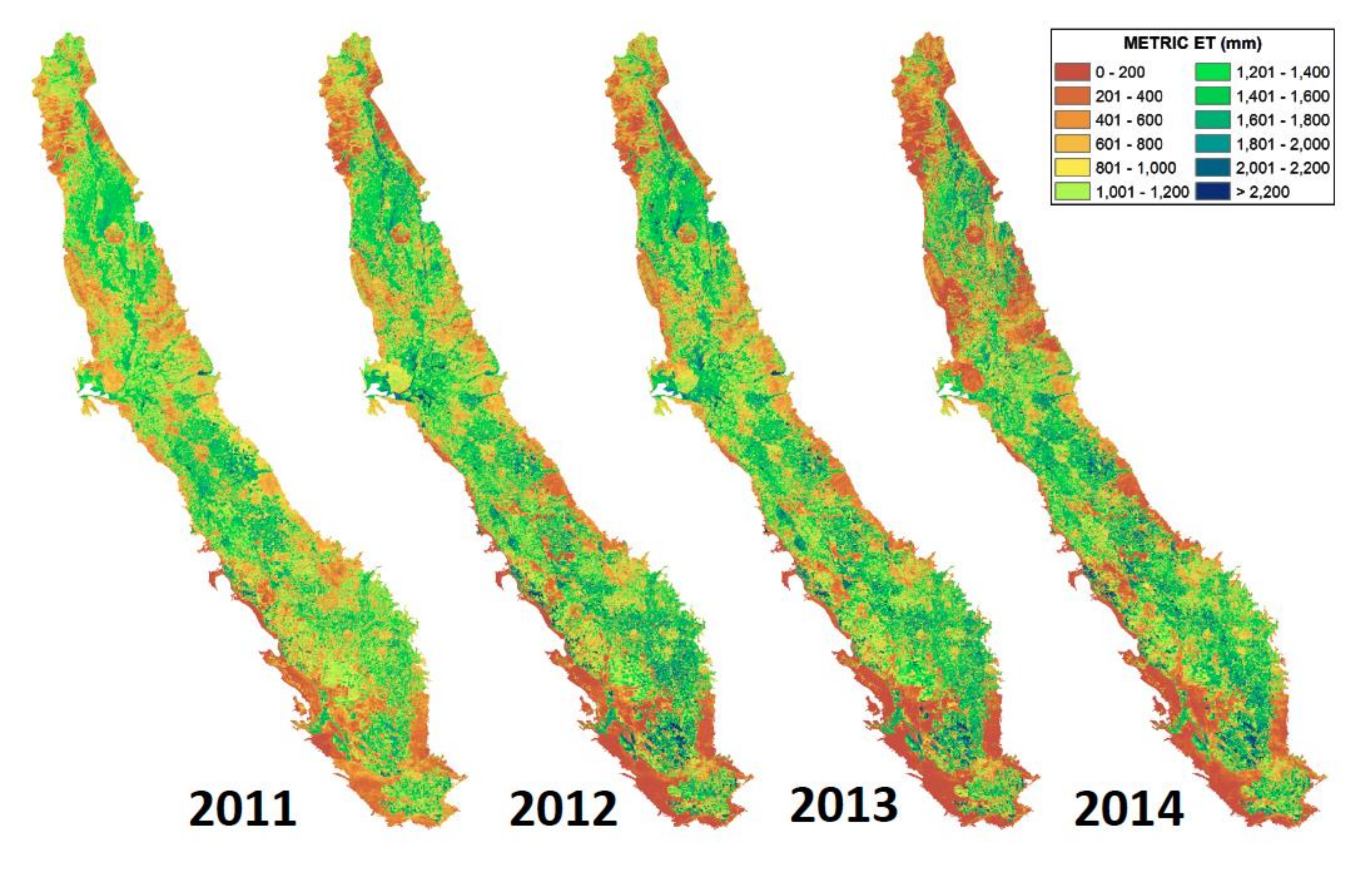
- Project History
- METRIC in Other States
- Kimberly R&E Center
- Landsat Thermal Band
- Workshops
- Presentations
- Evapotranspiration Data
- Map Server

IDWR Wins National Award from Harvard's Kennedy School of Government:

- Visionaries Video
- NASA video of IDWR program
- Washington Post - IDWR Mapping Evapotranspiration program
- Video of IDWR presentation before the National Selection Committee - May 2009
- NASA Landsat Evapotranspiration Information
- NASA "Image of the Day"
- Earth Observatory Feature Article

Allen et al., 2007. Satellite-Based Energy Balance for Mapping Evapotranspiration with Internalized Calibration (METRIC) –Applications. Journal of Irrigation and Drainage Engineering 133(4):395-406.

Highlights: Progress Toward METRIC Automation



Justin Huntington, Charles Morton, Desert Research Institute

Use of Monte Carlo approach to automate selection of hot and cold pixels.
Morton et al., 2013. JAWRA, 49(3):549-562

Limitations of the SIMS / Reflectance Approach

- Additional corrections needed for soil evaporation and crop stress (e.g., via METRIC or soil water balance)
- Only applicable for ag land cover; requires crop map

Strengths of the SIMS / Reflectance Approach

- Extensible framework for satellite data processing
- ET_{cb} represents biological demand for water by the plant
- Fully automated estimates at field scale
- NDVI data freely available from multiple satellites (e.g., Landsat 7, Landsat 8 and Sentinel 2A)
- Field scale estimates that account for weather conditions and observed crop canopy conditions
- Increasingly well-known uncertainty; small bias error

Combination of METRIC (energy balance) and SIMS (reflectance) approaches provides robust, long-term strategy for sustaining operational use.

Project Team

Forrest Melton, Lee Johnson, Kirk Post, Alberto Guzman, Carolyn Rosevelt, Gwen Miller, Aimee Teaby, Andrew Michaelis, Petr Votava, Rama Nemani
CSU Monterey Bay / NASA ARC-CREST

Kent Frame, Bekele Temesgen, CA Dept. of Water Resources

Partners:

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Problem Statement

- Increased access to information on crop evapotranspiration can support California growers in improving on-farm water use efficiency

- Information must be:
  1. Timely and reliable
  2. Specific to individual fields
  3. Easy to access
  4. Easy to use
  5. Accuracy of data must be clearly defined

- Project philosophy:
  - Irrigation management is complex → growers are in the best position to determine their crop water needs, *and,*
  - Better information leads to better decisions

Lessons Learned

1) Field validation and quantification of accuracy is critical, but also challenging in commercial ag settings

2) Partnership with growers / ag community is key, but requires sustained investment of time

3) Complexity and reliability are opposing forces → need for fallback algorithms

4) Needs for APIs to integrate with other tools → Collaboration creates success; competition creates confusion for stakeholders

1) Changes in California water law creating key opportunities for applications of satellite data for ET mapping

Benefits of Using Ag Weather Information in Irrigation Management

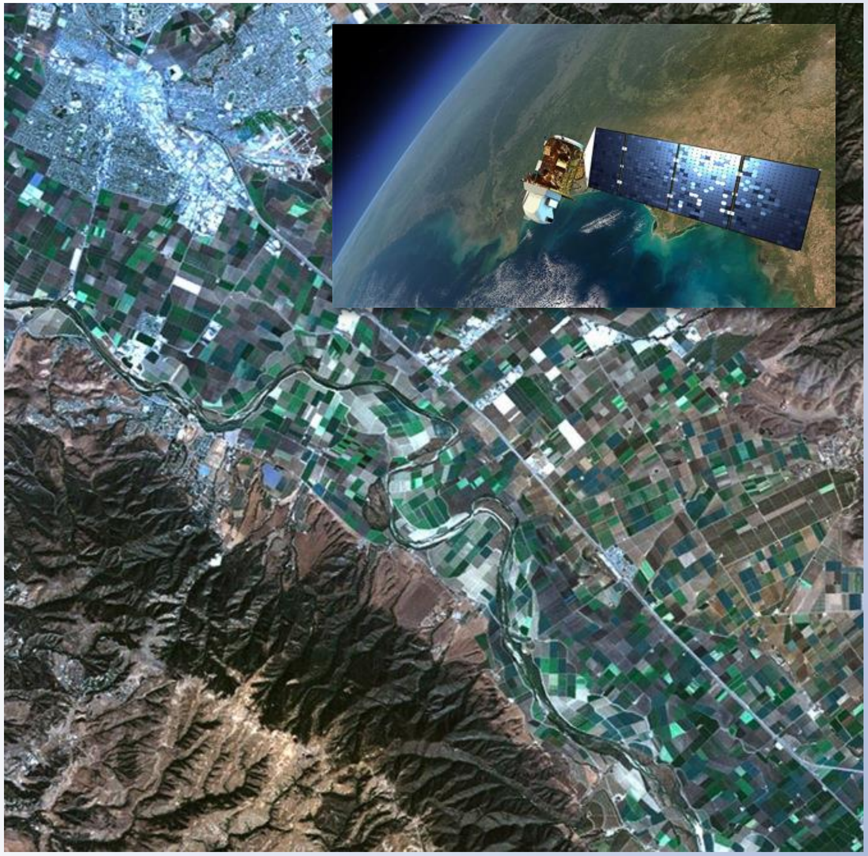
- California Department of Water Resources and UC Berkeley surveyed growers in 1990s
- Growers who utilized weather and ET_o data reported an increase in yields of 8% and a decrease in applied irrigation of 13% (DWR, 1997)

Method Used by Farmers to Decide When to Irrigate, USDA Farm & Ranch Irrig. Survey, 2008

	Percent of Farmers	
Method	CA	US
Condition of Crop	66%	78%
Feel of soil	45%	43%
Personal calendar schedule	32%	25%
Soil moisture sensing device	14%	9%
Daily ET reports	**12%**	**9%**
Scheduled by water delivery org.	11%	12%
Commercial or government scheduling service	10%	8%
When neighbors irrigate	6%	7%
Other	6%	9%
Plant moisture sensing device	3%	5%

Growers may report more than one method, so total of all methods may exceed 100%.

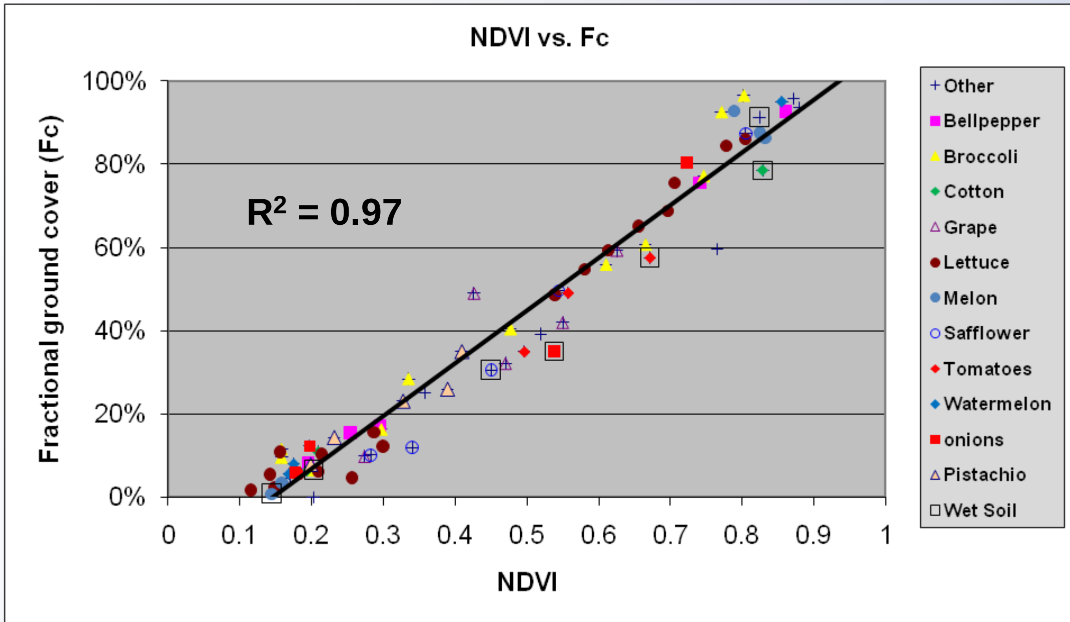
Satellite Data



Landsat (TM / ETM+ / OLI)
30m / 0.25 acres
Overpass every 8-16 days

Terra / Aqua (MODIS)
250m / 15.5 acre
Daily overpass

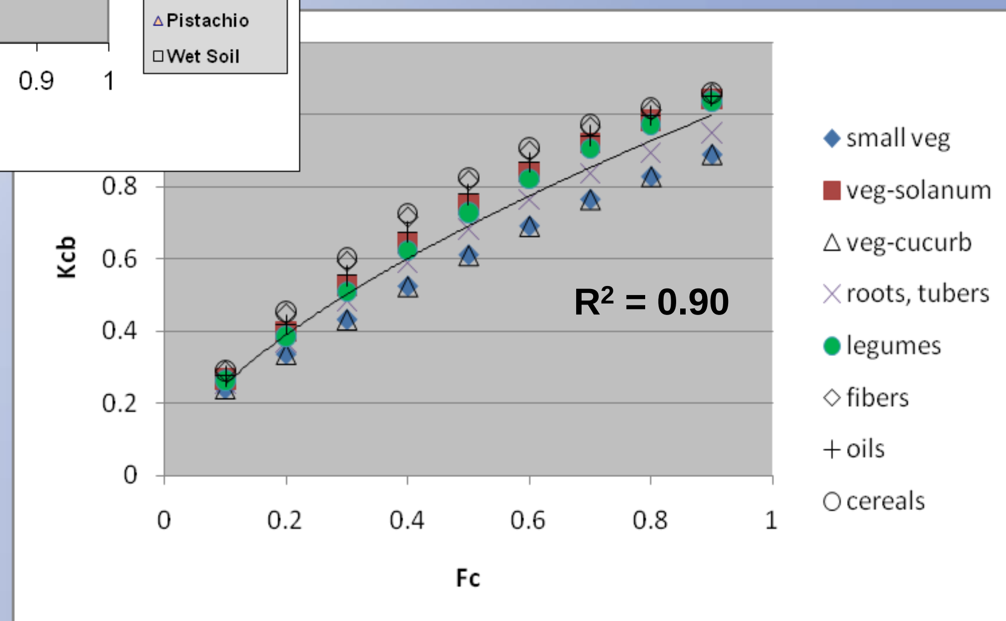
Approach: Mapping Crop Coefficients and Indicators of Crop Water Requirements from Satellite Data



Trout et al., 2008; Johnson & Trout, 2011

USDA studies provide basis for linking satellite vegetation indices (NDVI) to fractional cover.

Annuals



Studies by Allen & Pereira (2009) and others provide basis for linking fractional cover to K_{cb} for a range of crops.

Also see Bryla et al., 2010; Grattan et al., 1998; Hanson & May, 2006; Lopez-Urrea et al., 2009

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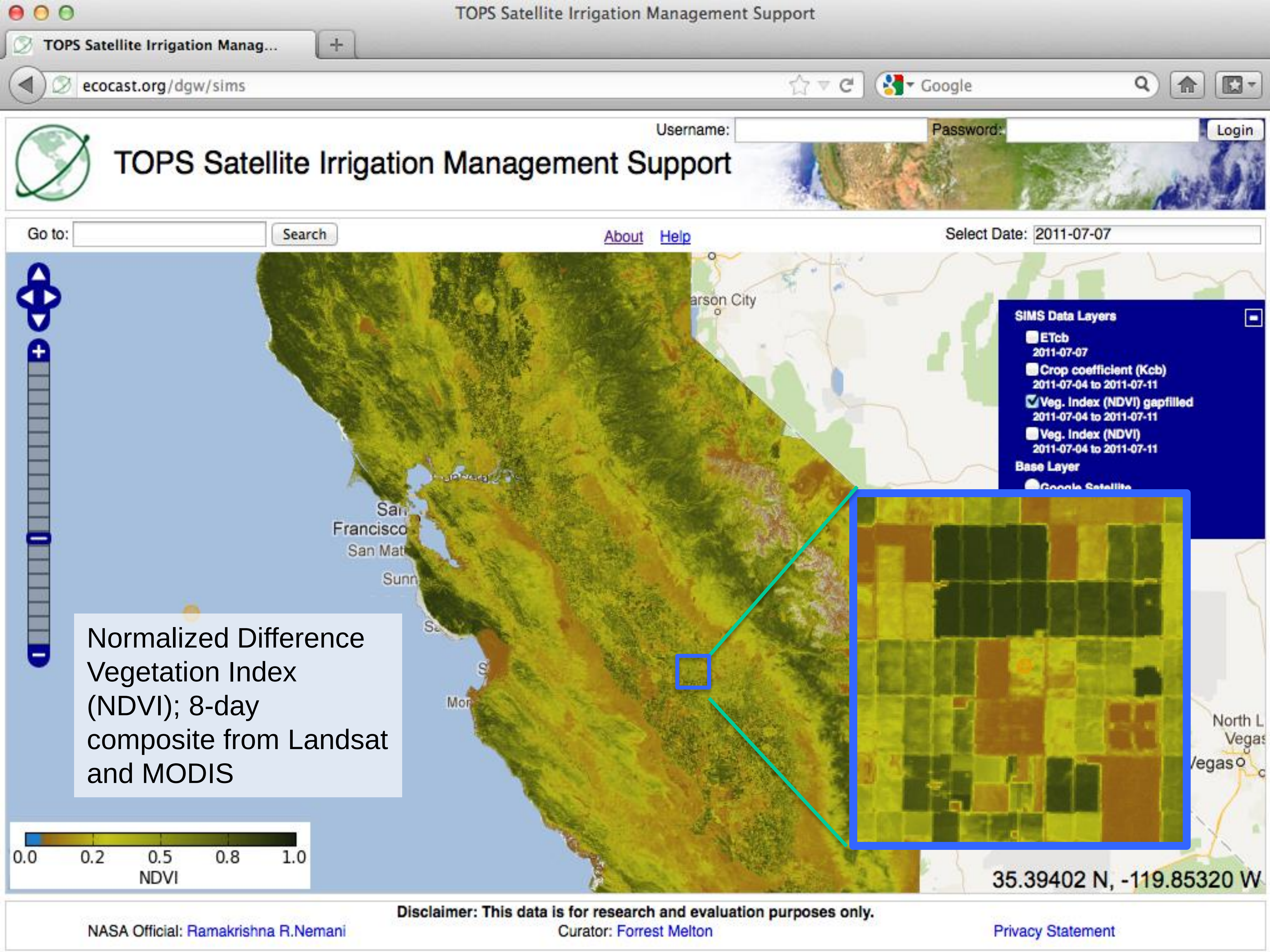
TOPS Satellite Irrigation Management Support
TOPS Satellite Irrigation Manag...
ecocast.org/dgw/sims
Google
Username:
Password:
Login
TOPS Satellite Irrigation Management Support
Go to:
Search
About
Help
Select Date: 2011-07-07
SIMS Data Layers
ETcb
2011-07-07
Crop coefficient (Kcb)
2011-07-04 to 2011-07-11
Veg. Index (NDVI) gapfilled
2011-07-04 to 2011-07-11
Veg. Index (NDVI)
2011-07-04 to 2011-07-11
Base Layer
Normalized Difference Vegetation Index (NDVI); 8-day composite from Landsat and MODIS
0.0 0.2 0.5 0.8 1.0
NDVI
35.39402 N, -119.85320 W
Disclaimer: This data is for research and evaluation purposes only.
NASA Official: Ramakrishna R.Nemani
Curator: Forrest Melton
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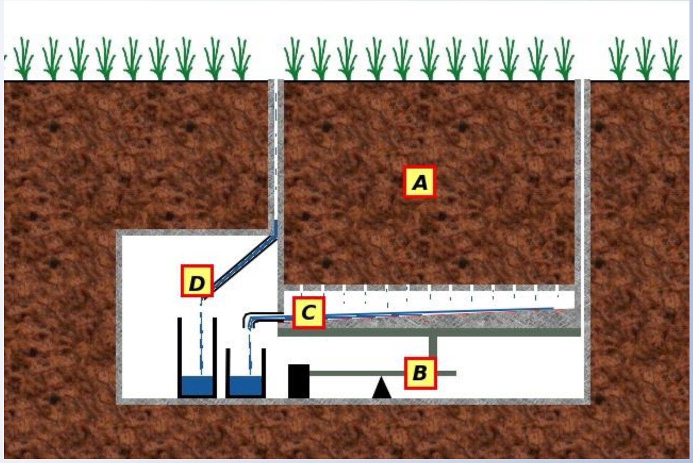
Approach: Mapping Crop Coefficients and Indicators of Crop Water Requirements from Satellite Data

NDVI vs Fractional Cover (Fc) relationships developed based on field studies to compare satellite and field measurements

Fractional Cover (Fc) vs Kcb relationships developed using weighing lysimeters, Bowen ratio stations, and eddy covariance



Credit: Wikipedia

Credit: USDA

Field Validation Strategy

Goal: Calculate daily ET for a wide range of crops and growth forms (graminoids, short forbs, tall forbs, vines, and trees) using two cost-effective and independent approaches at each site.

Approach 1) Water Balance: $ET = P + I - D - \Delta S$

Where ET is evapotranspiration, P is precipitation, I is irrigation, D is drainage below the root zone, and ΔS is change in volumetric water content

Approach 2) Surface Renewal Energy Balance:

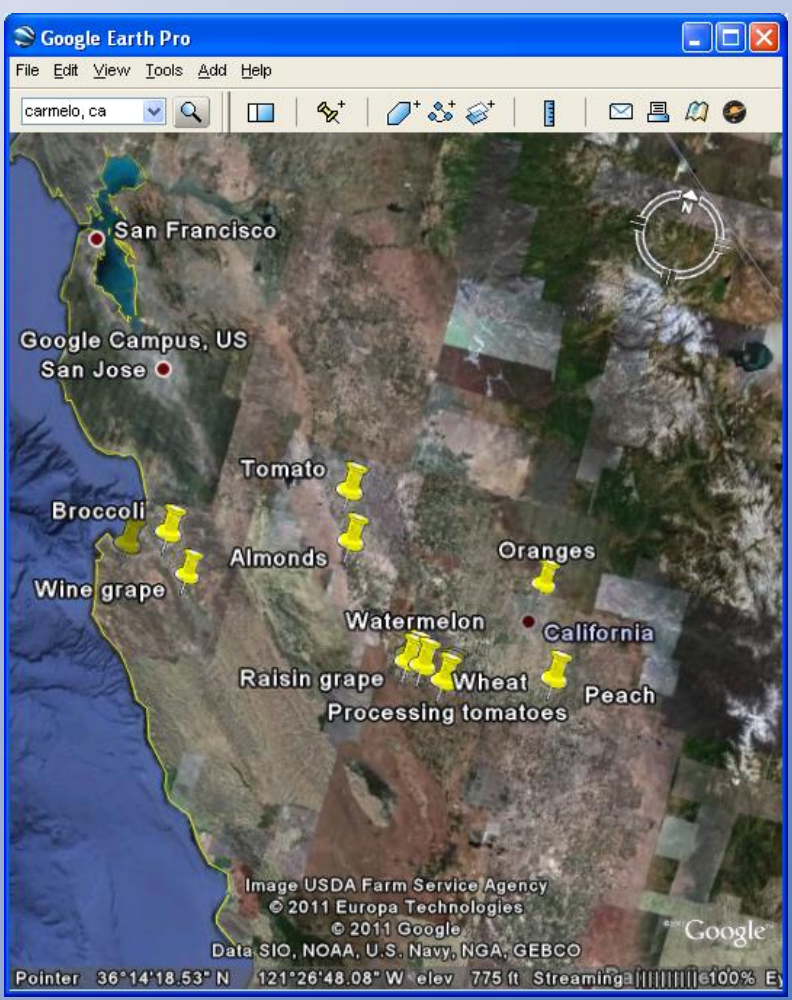
$$ET = R_n - H - G$$

Where ET is evapotranspiration, R_n is net radiation, H is sensible heat flux, and G is ground heat flux

Verification and Validation: Sensor Networks

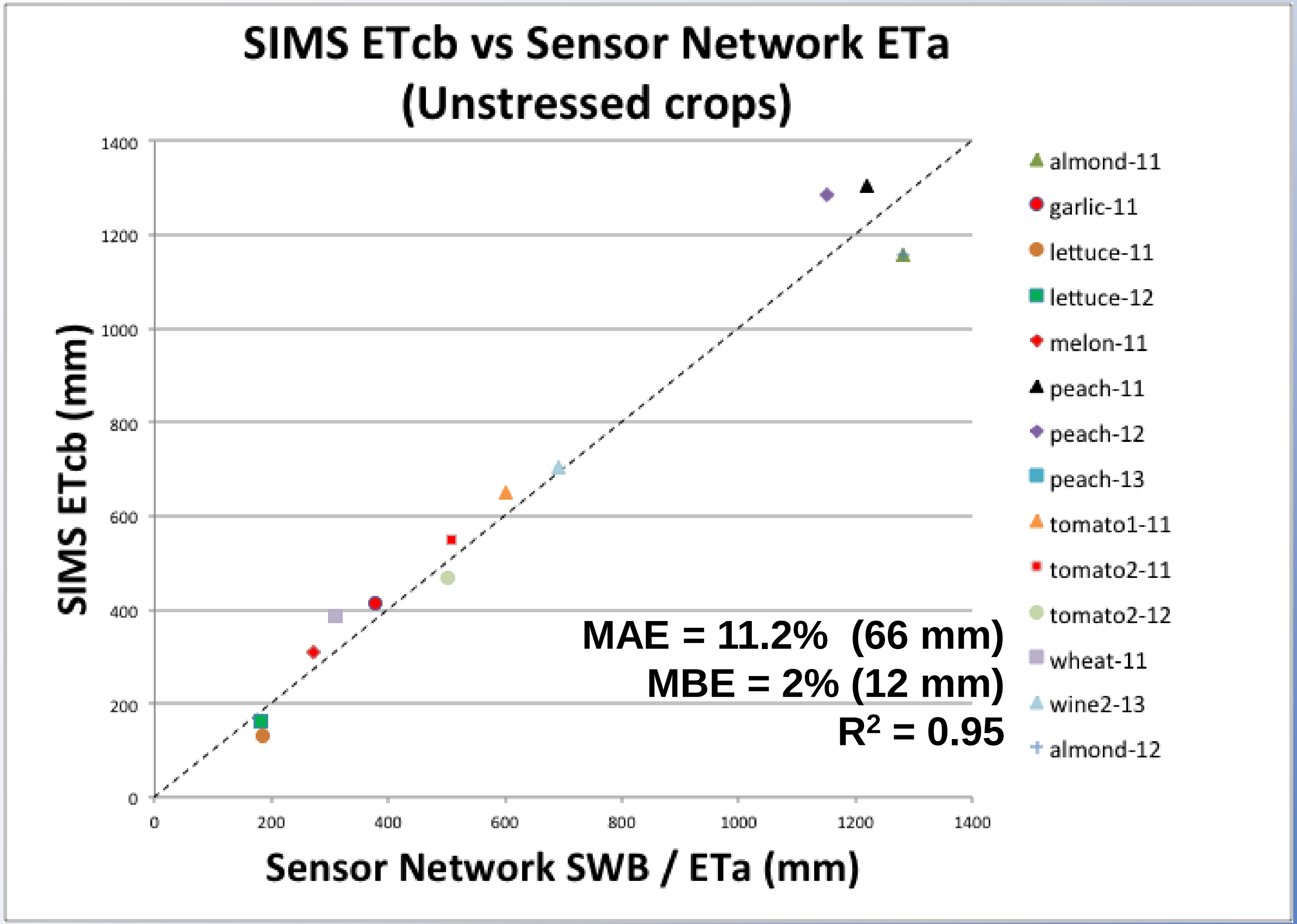
Sensor Network Installations

Crop Type	Crop	Location
Grain	Corn*	CSU Fresno
Grain	Wheat	San Joaquin Valley
Row	Garlic	San Joaquin Valley
Row	Lettuce*	SJ & Salinas Valley
Row	Broccoli*	Salinas Valley
Row	Cauliflower	San Joaquin Valley
Row	Tomato(2)*	San Joaquin Valley
Row	Cotton (drip)*	San Joaquin Valley
Vine	Melon	San Joaquin Valley
Vine	Wine grapes*	Salinas Valley
Vine	Raisins*	San Joaquin Valley
Tree	Peach*	San Joaquin Valley
Tree	Almond*	San Joaquin Valley
Tree	Orange*	San Joaquin Valley



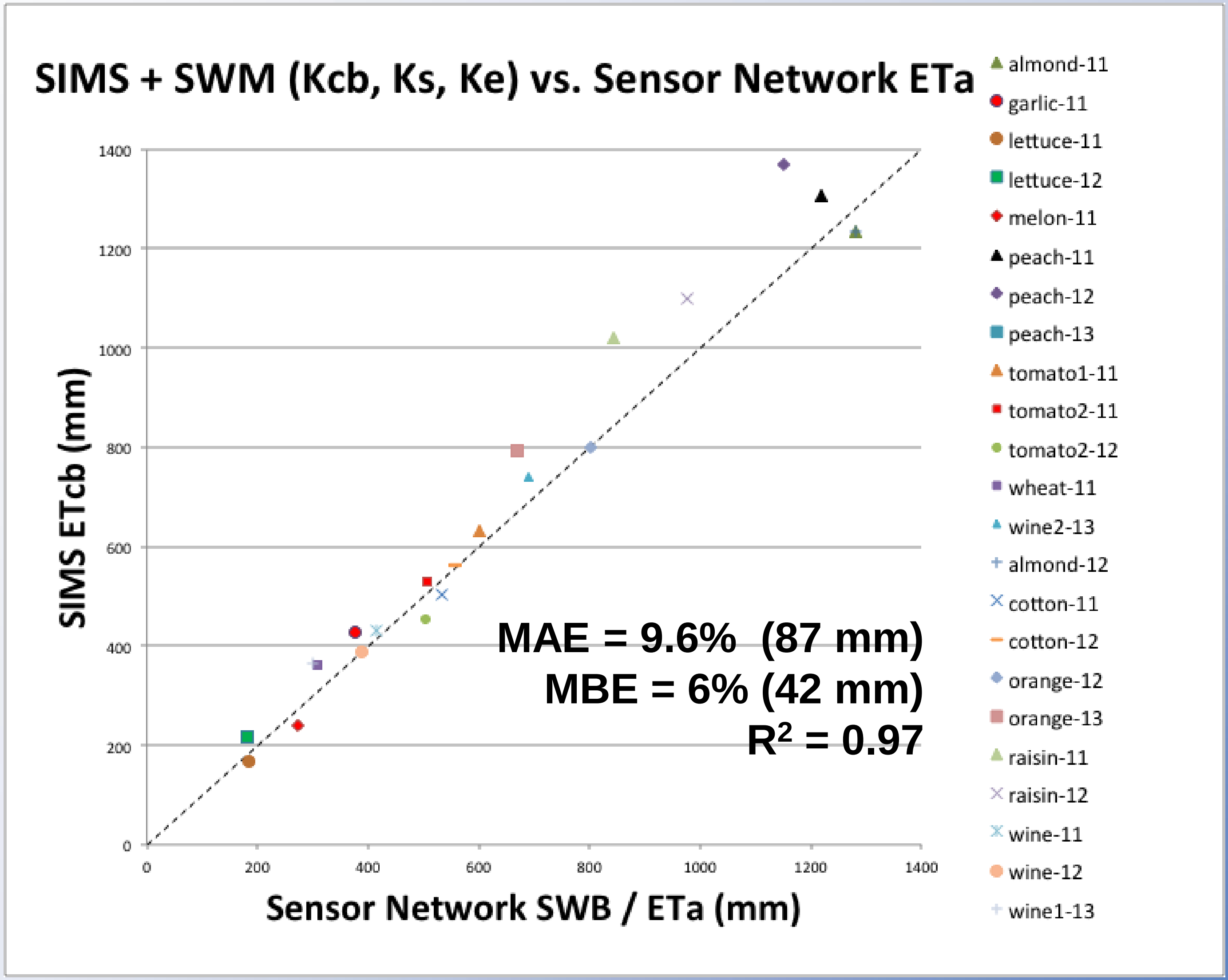
***Surface renewal instrumentation.**

Verification and Validation: Results to date



Comparison of seasonal ET totals from SIMS and the sensor network for sites instrumented in 2011-2013, excluding intentionally stressed crops (wine grapes, raisins, cotton, oranges).

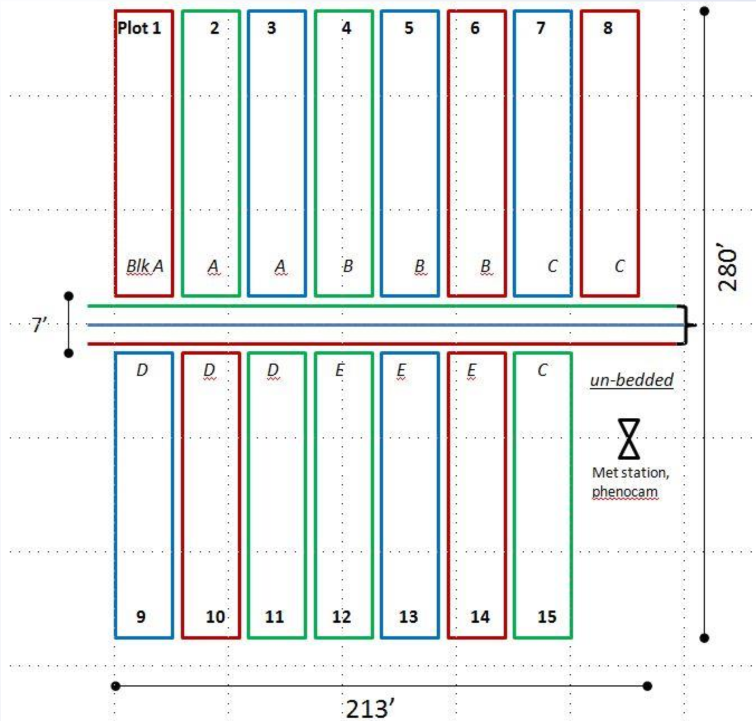
Verification and Validation: Results to date



Comparison of seasonal ET totals from SIMS and the sensor network for sites instrumented in 2011-2013. Ke and Ks coefficient via a soil water balance model based on FAO-56 (Allen et al., 1998).

Yield Trials

Lettuce & Broccoli
USDA ARS, Spence Road, Salinas



Treatments:

- Standard practice
- SIMS
- CropManage

- **3 tmts, 5 reps, block randomized design**
- **Total area: ~1.4ac (0.57 ha)**
- **Two years of data: 2012 & 2013**

PI: Lee Johnson; Co-I: Michael Cahn
Collaboration with UCCE, USDA ARS, Fresh Express, Tanimura & Antle

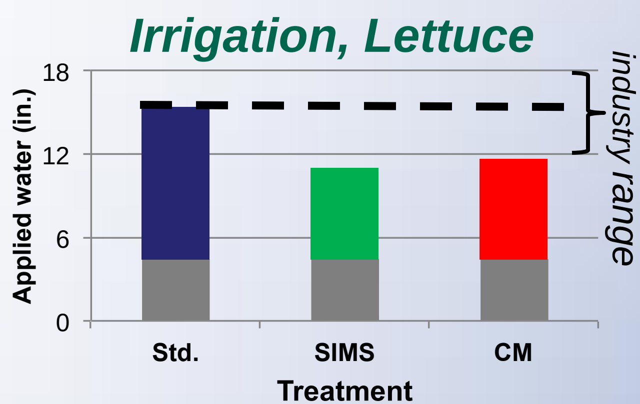
Yield Trials: Results to Date

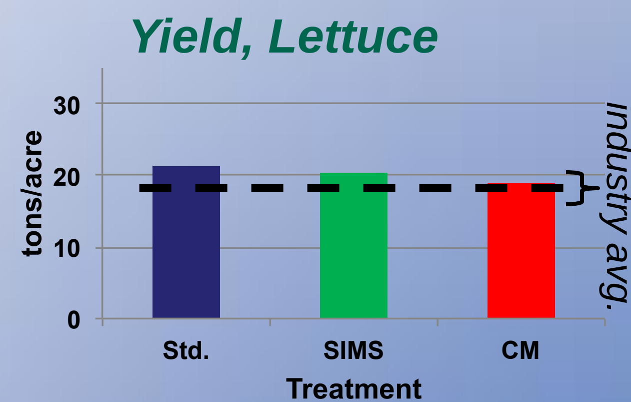
- Results to date confirm savings in applied water of 22-33% without reductions in yield or quality

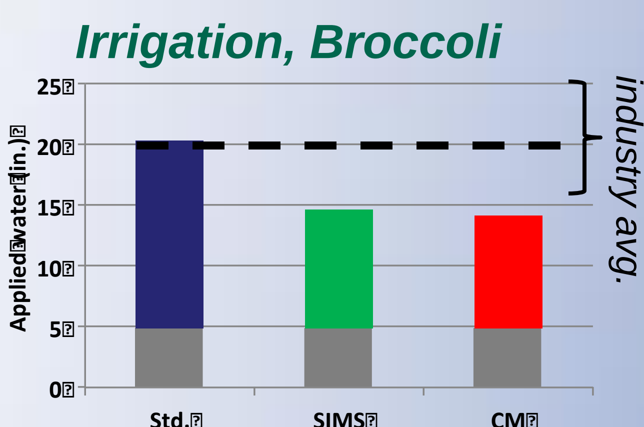
Standard practice

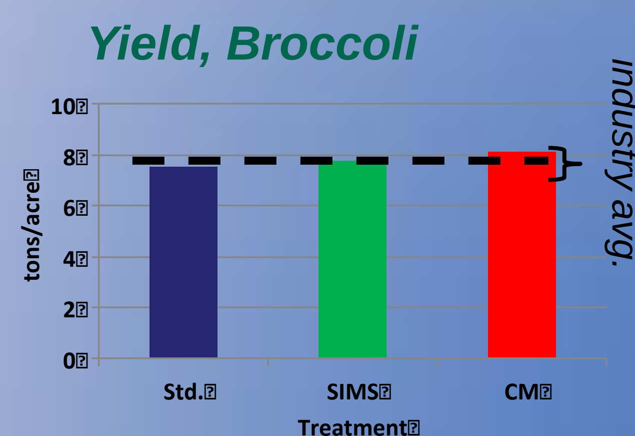
SIMS

CropManage







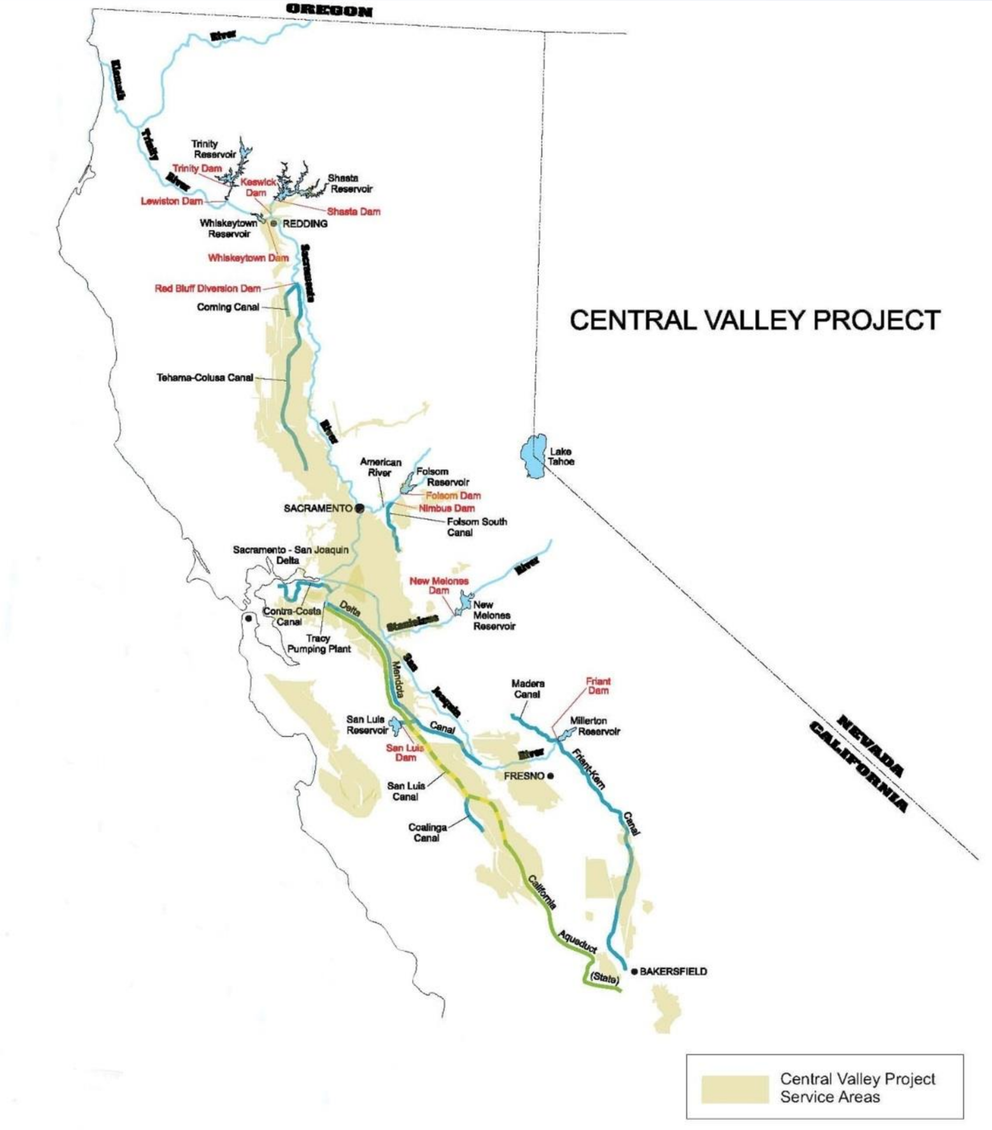


California Water Resource Management Challenges

- Drought impacts
- Competing demands
- Aging water conveyance infrastructure
- Groundwater overdraft
- Water quality and impaired water bodies
  - Nitrate, salinity, selenium

California State University
MONTEREY BAY
Extraordinary Opportunity

California Water Infrastructure



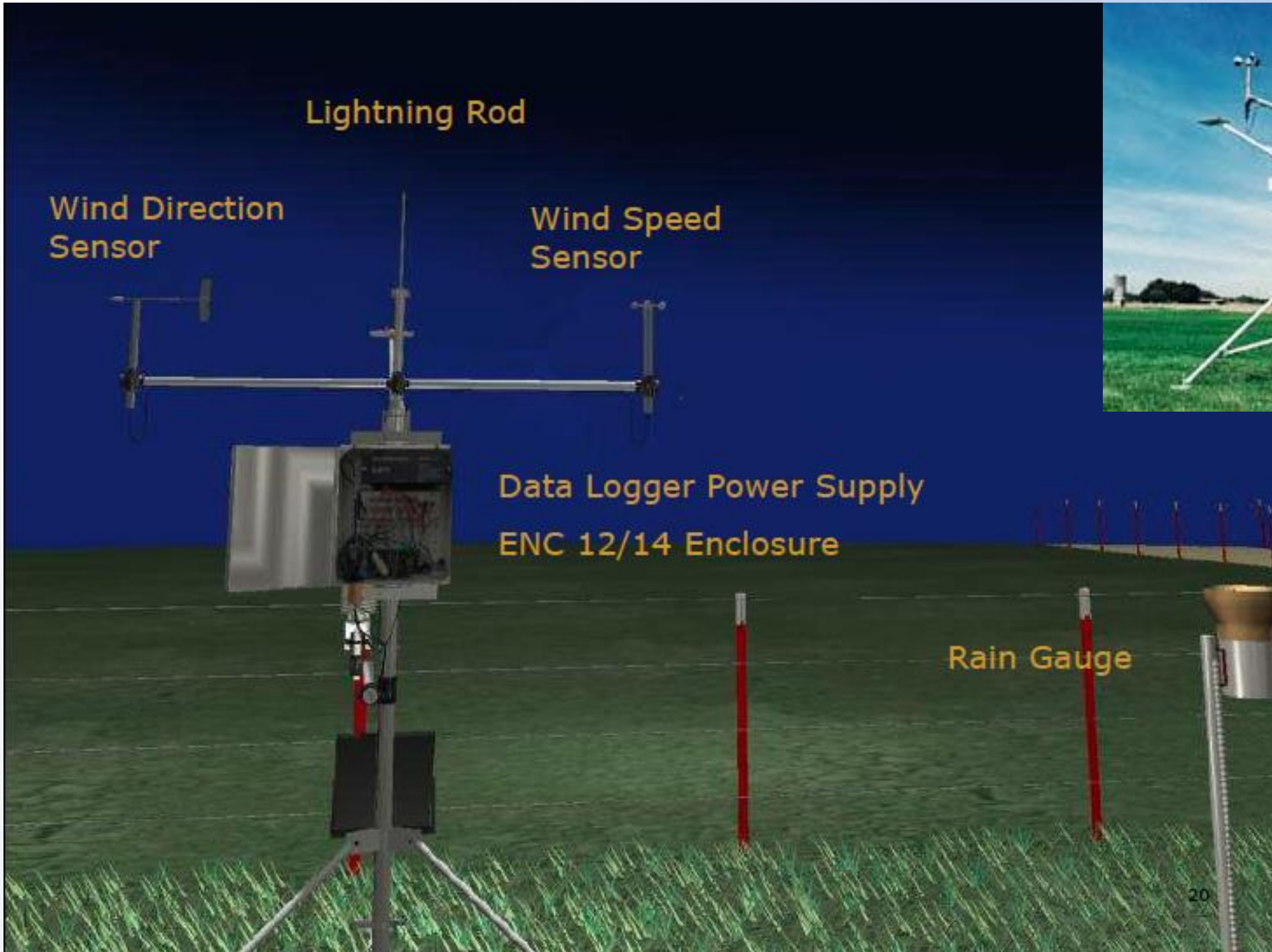
Central Valley Project

- 22 reservoirs
- 11 MAF (13.5 km^3)
- ~65% delivered in avg. year
- 1.21 million ha of ag irrig.
- 2 million people

State Water Project

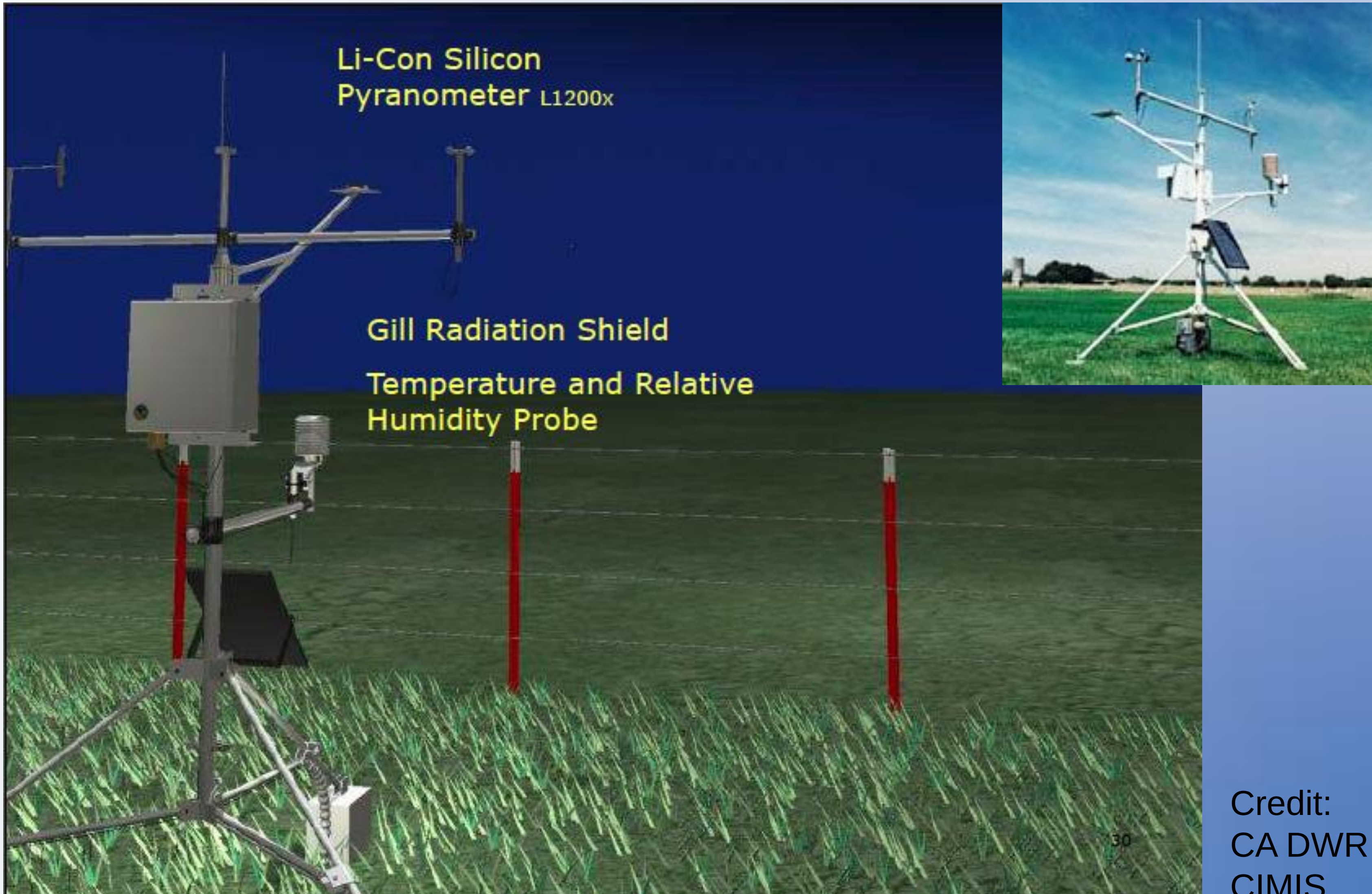
- 20 major reservoirs
- 5.8 MAF (6.2 km^3)
- ~50% delivered in avg. year
- 242,000 ha of ag irrig.
- 20 million people

California Irrigation Management Information System (CIMIS)



Credit: CA DWR / CIMIS

California Irrigation Management Information System (CIMIS)



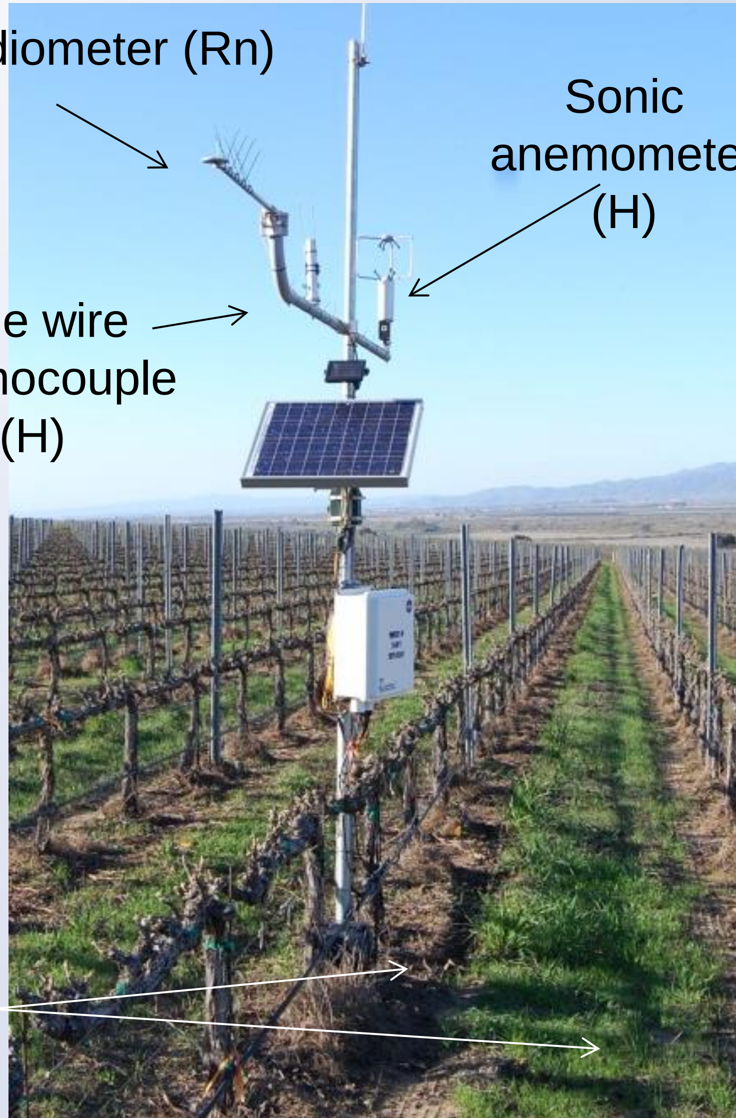
Credit:
CA DWR /
CIMIS

Surface Energy Balance / Surface Renewal

Net radiometer (Rn)

Sonic anemometer (H)

Fine wire thermocouple (H)



6 Soil heat flux plates (G)

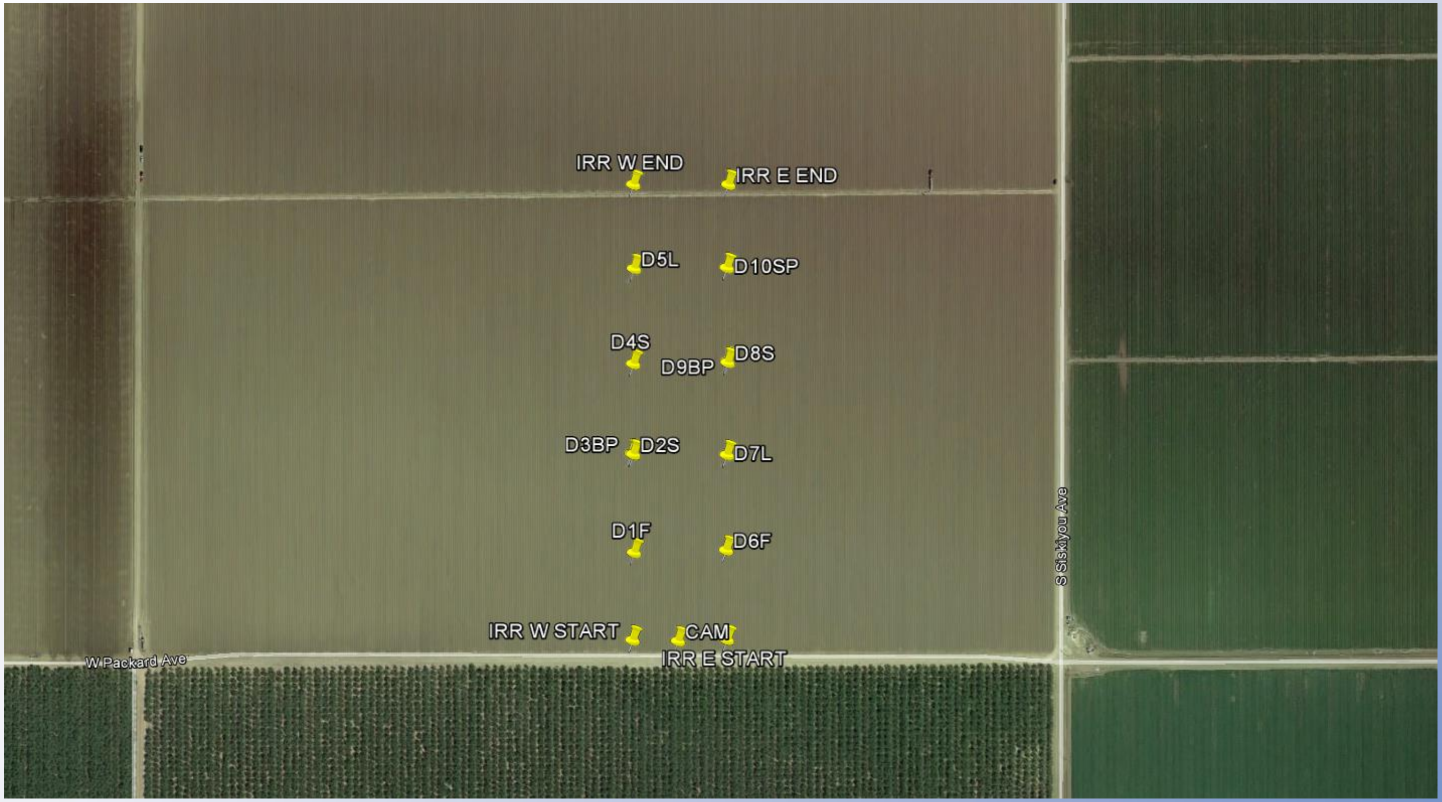
6 Soil averaging thermocouples (G)

Surface Renewal / Energy Balance Residual:

$$ET = R_n - H - G$$

Snyder, R. L., Spano, D., Duce, P., Paw U, K. T., & Rivera, M. (2008). Surface renewal estimation of pasture evapotranspiration. Journal of irrigation and drainage engineering, 134(6), 716-721.

Instrumentation Layout



<u>Point configuration (10):</u>

- P1 10HS 0-4”
- P2 10HS 12-16”
- P3 10HS 24-28”
- P4 MPS-1 14”
- P5 10HS 36-40” / G3 Passive Capillary Lysimeter 44”

<u>Other Instruments:</u>

- SR station
- MET station
- In-line flow meter

<u>Site Info:</u>

- Block #4
- Bed Width: 60”
- Furrow: 20”
- Between plants 20”
- Transplant-Double row
- 12” emitter spacing
- South to North flow

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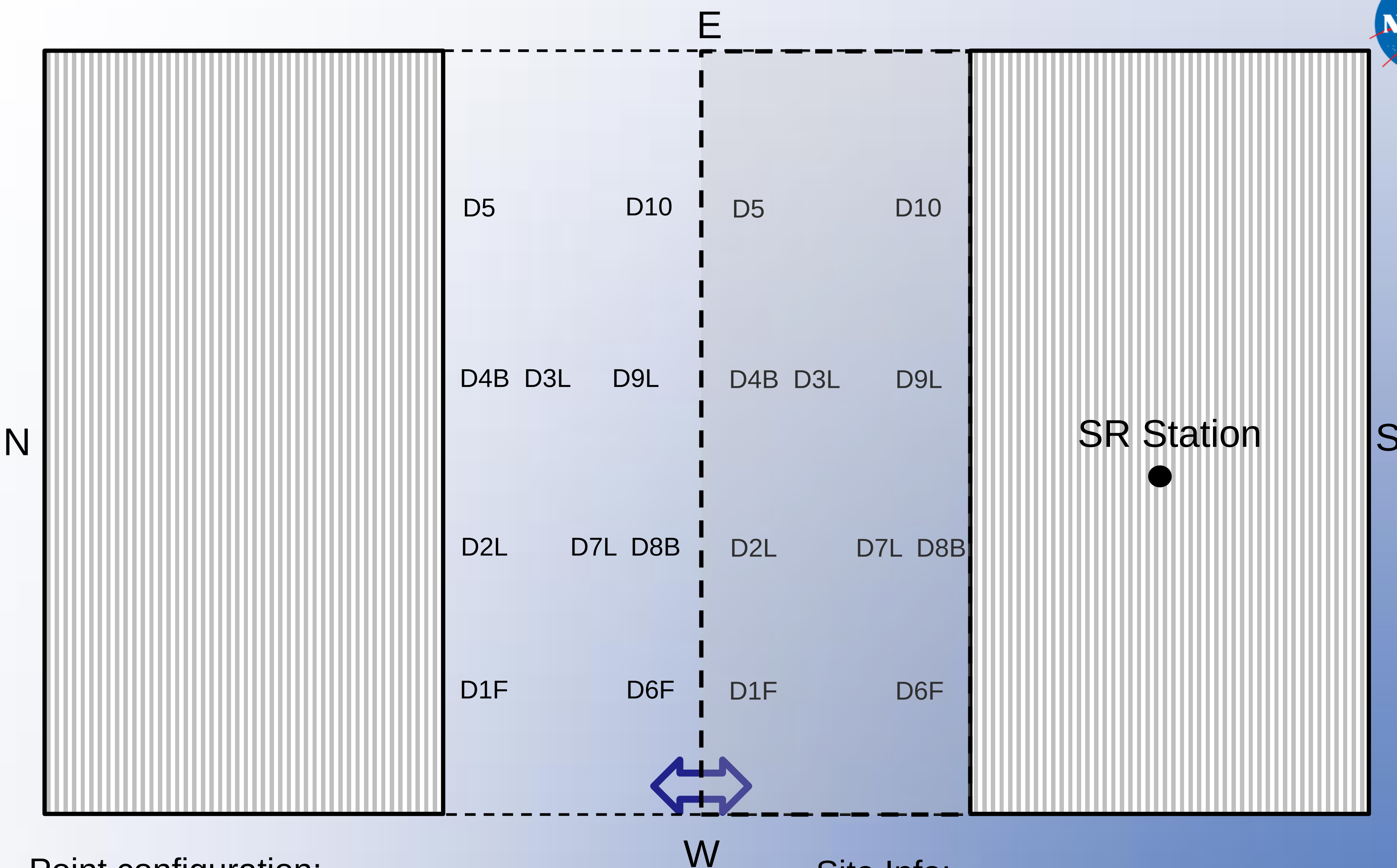


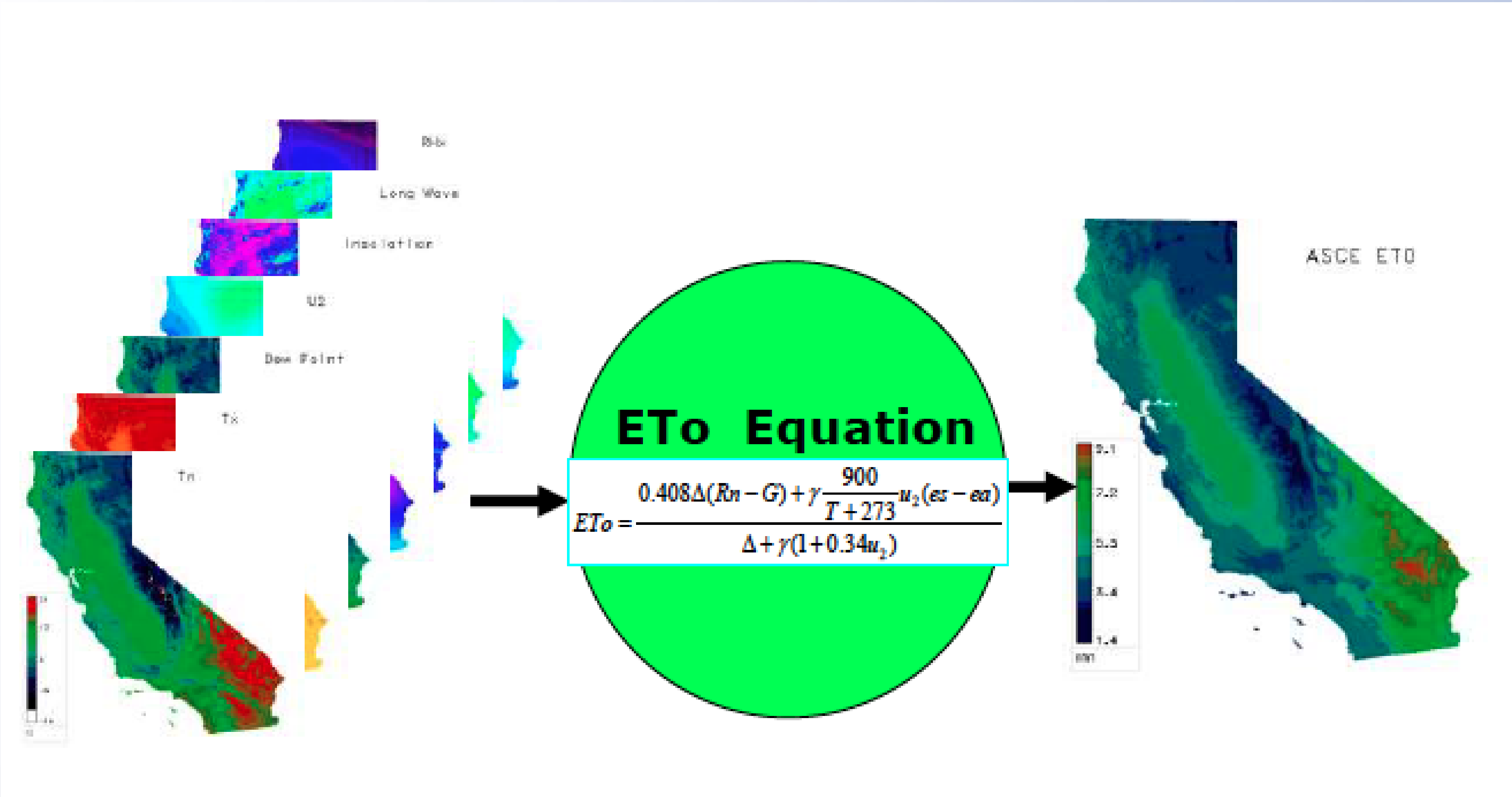
Point configuration:

- P1 10HS 0-4”
- P2 10HS 8-12”
- P3 10HS 16-20”
- P4 MPS-1 10”
- P5 10HS 24-28” / G3 Passive Capillary lysimeter 28-30”

Site Info:

- Seed spacing: 4.5”
- Dimensions: B 25”; F 16”
- 8” Emitter spacing (Med. Flow)

Spatial CIMIS
Statewide 2km Gridded ET_o



Credit:
CA DWR /
CIMIS